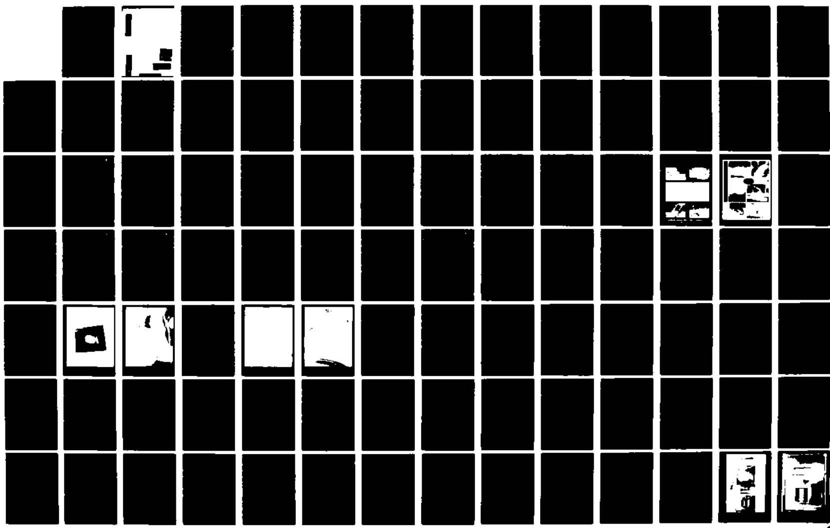
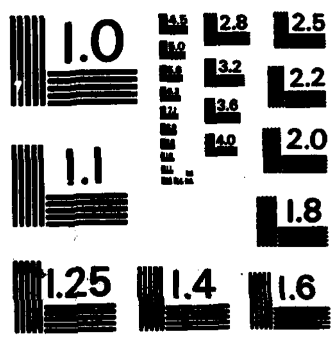
AD-A122 001 REMOTE CONTROLLED VEHICLE MOUNTED MINEFIELD DETECTOR SYSTEM(U) STANDARD MFG CO INC DALLAS TEX D W HUDLER ET AL. NOV 82 R6929-4 DAAK70-82-C-0052

1/2

UNCLASSIFIED F/G 19/1 NL




1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0

B. The degree of expected survivability must be examined. The same basic concepts presented in this study are applicable to both small light vehicles and large heavy vehicles. The vehicle can be protected from small arms fire and antipersonnel mines at a relatively low cost. A greater degree of protection requires use of massive armor increasing the size, weight and cost of the vehicle.

C. The intended mission of the RPGV detection system needs

R6929-4

REMOTE CONTROLLED VEHICLE MOUNTED MINEFIELD DETECTOR SYSTEM

Contract No. DAAK70-82-C-0052

November 1982

Final Report for Period February 1982 - August 1982

PREPARED FOR

U.S. Army Mobility Equipment
Research & Development Command
Procurement & Procution Directorate
Fort Belvoir, Virginia 22060

BY

Dennis W. Hudler and Kermit O. Taylor

The views, opinions, anu/or findings contained in the report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

Standard Manufacturing Company, Inc.
4012 W. Illinois Ave.
Dallas, Texas 75211

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER / 2. GOVT ACCESSION NO. AD-A122001	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) REMOTE CONTROLLED VEHICLE MOUNTED MINEFIELD DETECTOR SYSTEM	5. TYPE OF REPORT & PERIOD COVERED FINAL REPORT May 1982 - August 1982
	6. PERFORMING ORG. REPORT NUMBER R6929-4
7. AUTHOR(s) Dennis W. Hudler, Kermit O. Taylor	8. CONTRACT OR GRANT NUMBER(s) DAAK70-82-C-0052
9. PERFORMING ORGANIZATION NAME AND ADDRESS Standard Manufacturing Company, Inc. 4012 W. Illinois Ave. Dallas, Texas 75211	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS P/N 2A149020
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Mobility Equipment Research and Development Command Procurement and Production Directorate Ft. Belvoir, Virginia 22060	12. REPORT DATE November 1982
	13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report) UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Remote Controlled Vehicle
Countermine Operations
Detection Devices, Mines

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The purpose of this study was to determine the feasibility and optimum desig concept for a remotely controlled ground vehicle to locate mines and minefields. Evaluation was to be based on current technology, equipment and mission considerations, and threat assessment.

The envisioned vehicle utilization indicated the need for a lightweight, highly maneuverable vehicle equipped with radio controls, television monitor, minefield marking device, and a very good detection system. These features ar necessary to insure system survival, reliable operation, and provide standoff distance for operator safety. Addition of other equipment is also envisioned for us on special purpose missions, thereby increasing system utility and value. Al these pieces of equipment exist and can be operated using a remote control system,

BLOCK 20 (cont)

Vehicle mobility, maintainability, and cost factors indicate that the optimum vehicle configuration be a 6-wheeled all terrain unit utilizing hydrostatic drive and skid steering. Vehicle will be powered by a diesel engine for maintenance, efficiency, and logistical interface with current Army units. These systems are also readily adapted to remote control applications.

Accession For	
NTIS GRA&I	☒
DTIC TAB	☐
Unannounced	☐
Justification	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A	

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT)

TABLE OF CONTENTS (CONT)

LIST OF FIGURES, TABLES AND PHOTOGRAPHS

REMOTE CONTROLLED VEHICLE MOUNTED MINEFIELD DETECTOR SYSTEM

1.0 SUMMARY.

1.1 Purpose of Study.

The objective of this study is to determine the feasibility, advantages, and effectiveness of using a remotely controlled ground vehicle in the detection of mines and minefields. The scope of the study is limited to:

A. An investigation of the vehicle characteristics, configuration, and design criteria.

B. Criteria and parameters for interface with existing mine detection systems and sensors.

C. The relative advantages, disadvantages and cost effectiveness of various concepts.

This study is not concerned with development of new concepts in the field of mine detectors or sensors. Rather, it is an investigation of a new method of application for existing sensors, specifically, mounted on a remotely piloted ground vehicle (RPGV).

1.2 Methods and Approach.

The study was divided into four distinct phases.

A. Phase I - Task definition and analysis.

B. Phase II - Development of system concepts.

C. Phase III - Evaluation of concepts and selection of candidates for detailed investigation.

D. Phase IV - Investigation of selected system concepts.

1.2.1 Phase I.

Phase I was occupied with collection and analysis of data on mine warfare, countermine doctrine, and mine detection systems and sensors. Most of this data was in the form of reports, studies and technical manuals provided by the Countermine Laboratory (USAMERADCOM).

1.2.2 Phase II.

Analysis of the Phase I data provided a broad background in the methods used for mine deployment and potential countermeasures. Various system concepts were formulated which might have reasonable probability of meeting mission requirements.

1.2.3 Phase III.

The candidate Phase II concepts were evaluated with respect to overall mission effectiveness and practicality. The most promising of the concepts were selected for a detailed investigation in Phase IV.

1.2.4 Phase IV.

In Phase IV, the selected concepts were evaluated in detail with respect to:

A. Effectiveness, advantages and limitations

B. System cost

C. Operational constraints

1.3 Results of Study.

There is a large background of systems and technology available for the remotely piloted vehicle envisioned for this system and there is little doubt that a successful RPGV could be developed. The RPGV should be a small, lightweight, lightly armored, and low cost vehicle. It would be controlled from a remote station mounted in a secondary vehicle up to 2 kilometers distant.

The RPGV would be equipped with a relatively inexpensive video system to allow effective control and guidance of the vehicle.

The remotely piloted ground vehicle (RPGV) is capable of interface and effective operation with practically any type of sensors presently used or planned for use on ground or air vehicles. The effectiveness of the sensors would be substantially equal to the effectiveness in the normal mode of operation. There is one important criteria applicable to the RPGV (or, for that matter, to a manned vehicle to a slightly lesser degree) relating to sensor types which are sensitive to height above the ground. Survivability of the vehicle requires that the sensors be several feet in front of the vehicle mounted on retractable arms or a boom. It may be necessary for this boom (arms) to have several degrees of freedom to allow positioning and sweeping of the sensors. With the vehicle travelling over rough and undulating terrain, it would be most difficult to accurately control sensor ground clearance manually under these conditions at any significant ground speed. Development of a closed loop feedback system to automatically and accurately control sensor height above ground and prevent the sensors from striking external objects (rocks, tree roots, etc.) is a formidable task. In fact, this task would be analogous to the very complex problems associated with detection of the actual mines. The only systems really practical for the RPGV are those which allow sensor operation in a range of about 1/2 to one meter above ground.

In addition, the potential threat is so broad that there is not a sensor or detection system which stands out as the optimum device for all mine warfare tactics and scenarios. Complete coverage of the entire threat spectrum may require coupling more than one type of sensor to the RPGV.

1.4 Conclusions.

Present technology provides sensors and detectors which are operable in an air vehicle, ground vehicle, or carried by personnel. Airborne sensors can be effective in identification of a minefield but suffer from three major limitations.

A. Limited effectiveness in identification of individual mines.

B. No practical method for identification of individual mine locations or route marking.

C. Mission time is normally severely restricted by fuel limits and aircraft survivability.

Portable detectors such as the AN/PRS-8 and AN/PSS-11 are reasonably effective but are slow and place the operator in an extremely vulnerable situation. It is almost self-evident that use of portable detectors should be relied on as a back-up or last resort system rather than the primary method for off-route mine detection.

Considering the limitations of airborne sensors and portable detectors, the optimum system seems to be sensors mounted on some type of ground vehicle. This ground vehicle could be either manned or remotely controlled. However, in a manned vehicle, personnel are again vulnerable to enemy fire or, at least, the vehicle must be armor plated to afford a reasonable degree of protection. In a manned vehicle, armor is an absolute necessity while, in an RPGV, it is an option which can be, if desirable, traded away in favor of other options and alternatives. The advantage in using an RPGV for mine and minefield detection is simply that personnel are not exposed to an extremely hazardous environment. An RPGV could be much smaller, lighter, more reliable and maintainable and much less expensive than a manned vehicle for the same task. The RPGV could probably be designed sufficiently inexpensive as to be expendable under certain conditions.

An additional advantage of an RPGV would be a significant improvement in operator efficiency and effectiveness. Operation of sensors and analysis of feedback data requires skill, alertness, and concentration. Exposure to a hazardous environment results in operator stress, fatigue, and rapid deterioration in efficiency and performance. An RPGV would place the operator in a much safer, less stressful environment more conducive to the high level of human performance required for mission success.

There are a number of real advantages in use of a RPGV for off-route mine detection. In addition, such a vehicle could be very useful for reconnaissance of contaminated areas and remote observation. The concept seems practical and potentially more effective than the alternatives. However, should a development program be considered, there are several basic questions which should be resolved beforehand.

A. The benefits of the system would be greatly enhanced if it contained some degree of mine neutralization capability. However, this could greatly increase the size and cost of the vehicle.

B. The degree of expected survivability must be examined. The same basic concepts presented in this study are applicable to both small light vehicles and large heavy vehicles. The vehicle can be protected from small arms fire and antipersonnel mines at a relatively low cost. A greater degree of protection requires use of massive armor increasing the size, weight and cost of the vehicle.

C. The intended mission of the RPGV detection system needs to be clearly defined in detail. The approach of this study has been to examine the RPGV concept against the backdrop of mine warfare, in general. However, the threats are so many and varied that a single vehicle capable of effective countermeasures against all possible scenarios would be complex and expensive. The mission profile needs to be narrowed while still maintaining sufficient capabilities that the RPGV is effective against the major threats. For example, antipersonnel mines pose a limited threat to equipment and can be neutralized by several low risk, rapid and effective methods. Perhaps antipersonnel mines should be countered by neutralization rather than detection and marking. Detection and marking of antitank mines then becomes the primary mission of the RPGV system. In addition, it may be that surface mining is the primary threat. Detection of surface laid or scattered mines is, in many respects, a simpler problem than detection of buried mines.

This study was not intended to define the vehicle mission or determine the primary areas of threat. However, this should be accomplished before initiating a development program.

2.0 PREFACE.

2.1 Authorization for Study.

This report is submitted in accordance with contract number DAAK70-82-C-0052 and the Contract Data Requirements List (CDRL) item A002 and covers work authorized by the above listed contract. This report has been prepared by:

Standard Manufacturing Company, Inc.

4012 West Illinois Avenue

P. O. Box 210300

Dallas, Texas 75211

214/337-8911

The authors are:

Dennis W. Hudler

Kermit O. Taylor

The principal investigators were:

Dennis W. Hudler (Project Engineer) and

Kermit O. Taylor (Design Engineer)

2.2 Acknowledgements.

The Contractor would like to acknowledge the invaluable assistance and cooperation of the Countermine Laboratory (USAMERADCOM), Fort Belvoir, and, in particular, Mr. Stephen F. Schaedel, Project Officer.

3.0 COPYRIGHT PERMISSION.

There is no copyrighted material contained in this report.

4.0 TECHNICAL REPORT.

4.1 Introduction.

4.1.1 Purpose.

This study is concerned with development and analysis of system concepts for a remotely piloted ground vehicle (RPGV). This vehicle will be utilized in a countermine role for detection of mines and minefields. Interface with existing mine sensors and detection systems is also examined. The study outputs are specific technical and operational parameters and criteria for a RPGV mine detection system.

4.1.2 Task Definition - Phase I.

The current primary system for off-route mine detection is portable mine detectors. These detectors are slow and expose the operator to enemy fire, NBC contamination and antipersonnel mines, especially tripwire fuzed mines. Because of operator vulnerability, the survivability of the system is correspondingly very low. One possibility for increasing the speed of operation and system survivability is mounting of sensors and detectors on a ground vehicle. This vehicle could be either manned or unmanned (remotely controlled). This study will be concerned exclusively with the second alternative.

There are two major categories of mines; antitank (AT) and antipersonnel (AP). As the name implies, antitank mines are relatively large, frequently metallic, and intended to destroy or disable tanks and other large vehicles. They are normally placed several meters apart to prevent secondary detonations. Antipersonnel mines are much smaller and less powerful. They may be either metallic or nonmetallic. Antipersonnel mines could be placed much closer together than AT mines. The primary methods for activation of an AP mine are pressure contact and tripwire fuzes. Antitank mines are actuated by pressure contact, proximity of large metallic objects and seismic or acoustic disturbances.

4.1.2.1 Minefield Laying Tactics.

Mines may be placed by three distinct methods.

A. Buried. Mines can be buried some distance below the ground surface. Normally, they will not be covered by more than 4 to 6 inches of earth. Mines may be buried manually or by a minelaying machine. Mechanized minelaying is primarily associated with AT mines. The mines would be in rows or belts 10 to 30 meters apart with AT mines spaced 4 to 5 meters along each row.

B. Surface Laid. Mines may be placed on the surface of the ground by either personnel or machine. Mines placed by ground personnel would normally be camouflaged or reasonably well hidden.

C. Scattered. Scattered mines will also be lying on the ground surface. The distinction between scattered and surface laid mine is the method used for dispersal. Scattered mines will be laid down by aircraft or artillery. As such, they will have a more random pattern. A minefield laid down by scattering could be characterized by areas of high and low concentrations of mines. There may be "belts" or clear paths around "pockets" of relatively high density concentrations. Scattered mines will be visible unless they are naturally camouflaged by the terrain such as tall grass. Scattered mines may also be covered by natural forces such as snow or blowing sand.

Typically, a minefield will be protected by enemy "snipers", artillery observers, or an enemy force in defensive positions. This prevents or hampers breaching of the minefield.

4.1.3 Development of System Concepts - Phase II.

The objective of this study is to develop the system parameters and operational criteria for an RPGV mine detection system which has optimum effectiveness against the minefield laying tactics outlined above. Countermine warfare is divided into two major categories:

A. Detection and marking of mines

B. Neutralization of mines

The primary mission of this system is detection and marking. However, consideration will be given to limited use in a neutralization capacity against antipersonnel mines.

The contract for this effort lays down the following ground rules.

A. The system will be used for off-route mine and minefield detection.

B. The system will be composed of sensors mounted on a remotely piloted ground vehicle (RPGV).

Within these ground rules, we have attempted to systematically analyze every possible alternative. Many alternatives are

SUMMARY OF THE THREAT

I. Classification of Mine Types

  A. Antitank

  B. Antipersonnel

  C. Metallic and nonmetallic

II. Method of Placement

  A. Buried

    1. By ground personnel

    2. By minelaying machines

  B. Surface laid

    1. Intentionally camouflaged

    2. Naturally camouflaged

    3. Covered by natural forces such as snow, blowing sand, etc.

    4. Visible

  C. Scattered from aircraft or artillery

    1. Naturally camouflaged by terrain

    2. Visible

    e. Covered by natural forces

  D. Type of Fuzing

    1. Contact pressure

    2. Magnetic

    3. Seismic

    4. Acoustic

    5. Trip wire

III. Minefield May be Defended by Small Arms Fire or Artillery simply listed and immediately discarded as impractical or inconsistent with overall system requirements. Other alternatives are investigated in detail.

The system is composed of three major elements. The remotely piloted ground vehicle (RPGV) is one element of the system. The RPGV will be a self-propelled machine capable of being driven and controlled by any operator located some distance away. The second element of the system is the mine detectors and sensors. The appropriate sensors and detectors will be mounted on the RPGV. The third and final element is the remote monitor and control system. This element is composed of those devices, controls, television monitors, transmitters, receivers, etc. which are necessary for operation of the RPGV and mine sensors from a remote location.

In order to perform a logical and systematic investigation, the three major elements were subdivided in accordance with the outline given below. Each subelement is then the target of a detailed investigation.

A. RPGV design parameters and criteria
   1. Undercarriage
      a. Tracked
      b. Wheeled
   2. Traction system
      a. Mechanical transmission
      b. Hydrostatic
   3. Power plant
   4. Vehicle physical and operational characteristics

5. Vehicle control system

6. Vehicle guidance system

7. Survivability

B. Detector interface

1. Mechanical interface design

2. System interface

3. Television systems

4. Marking systems

C. Monitor and Control System

1. Vehicle

2. Sensor

3. Sensor data feedback

4.1.4 Evaluation of Concepts and Selection of Candidates for Detailed Investigation - Phase III.

The three major elements of the RPGV Detector System (vehicle, sensors, and monitor) have been briefly defined above. Except for the limits imposed by contract definition, there are a large number of possibilities for each of these elements. Before starting a detailed investigation, it is necessary to eliminate those possibilities which seem counterproductive, impractical, or simply not worth the time and effort. This will allow narrowing the field of study and concentrating effort on those concepts which seem to show the most promise.

4.1.4.1 Large, Heavily Armored vs. Small, Lightly Armored.

The primary system presently used for off-route mine detection are the man portable AN/PRS-8 and AN/PSS-11. The primary objective is to develop a system which will be faster and have better survivability than this existing system. A ground vehicle with limited or no armor will meet both of these objectives.

It seems reasonable that a mine detection system should be capable of operation in an AP and AT mine environment with a low probability of being destroyed or disabled by the mines. In fact, tripwire fuzed AP mines are likely to be detonated by passage of the vehicle since it is not likely that any sensor will be capable of detecting tripwires. Scattered mines may also be tripwire fuzed and, in this case, it is probably impossible to negotiate a path through the minefield without causing a number of explosions. Survival in an AP minefield would seem to require some degree of light armor to protect vital components of the vehicle and sensors.

A different type of threat is presented by high density AP minefields. Even a small vehicle could be "boxed in" and unable to find a path sufficiently wide to allow maneuvering through the mines. The probability of encountering such a "high density" AP minefield is not known. However, if this is a real threat, mission success could depend on the vehicle having the capability to neutralize the mines and clear its own path.

Survival in an AT minefield will depend on not detonating a mine in close proximity to the vehicle. It is not practical to consider a vehicle design capable of surviving a close AT mine explosion for this type system. Doing so would dictate a large vehicle with massive armor. This is counterproductive since the mines and minefield were designed to prevent passage of exactly this type of massive vehicle. The mission requires detection and marking of mines. It follows that the vehicle must be small enough to negotiate a path around detected mines without disturbing those adjacent. It could be impossible to maneuver a large, massive vehicle through an AT minefield. A small, lightweight vehicle has a higher probability of mission success. The primary method of survival in an AT minefield will be detection and avoidance rather than massive armor. This depends on a small, highly maneuverable vehicle with a good AT mine sensor.

The system operational requirements indicate that the RPGV will likely be subjected to explosion of AP mines at least in close proximity to the vehicle. The capability of surviving a direct contact AP mine explosion is also very desirable, although perhaps not a firm requirement. The degree of required survivability against direct contact explosions depends on the effectiveness of the sensor system. If the system is highly effective and reliable, the RPGV will seldom be exposed to a direct contact explosion and it may not be a cost effective to consider such a limited threat.

Antitank mines are designed to disable or destroy battle tanks and it is not practical for the RPGV to be more survivable than a battle tank. The approach to survival in an AT minefield will be to detect and avoid the mines. This will require a small, lightweight and possibly relatively quiet vehicle which is highly maneuverable.

Current Army inventory does not contain a small lightly armored vehicle capable of meeting the required maneuverability and survivability factors. The last known U.S. Army vehicle having these size, armor, and maneuverability characteristics was a scout vehicle modeled after the M-113 Armored Personnel Carrier. These scout vehicles were phased out of service several years ago and were frequently placed on tank and artillery impact areas.

The factors of cost, reliability/maintainability, and logistical interface will be addressed later in this report. In each case, purchase of small lightweight vehicle is the optimum solution.

4.1.4.2 <u>Method of Remote Control</u>.

There are two primary methods for remote control of the RPGV.

A. Through an umbilical by either electrical signals transmitted over wires or using optical fibers.

B. Transmission of signals by carrier wave, i.e., radio, television, and microwave.

The disadvantages of an umbilical are obvious and include mainly:

A. Short practical range or distance between the RPGV and the controller.

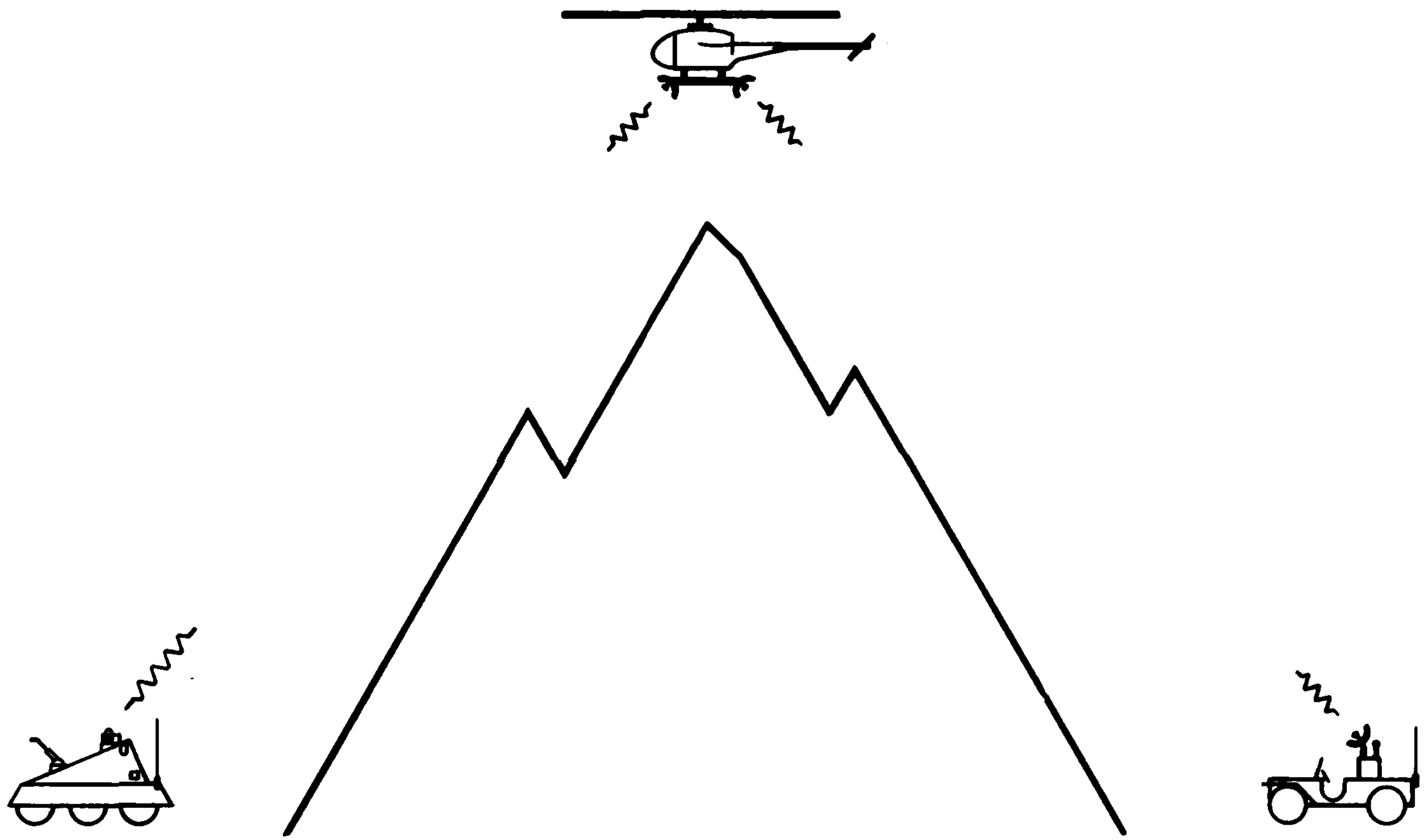
B. High probability of the vehicle becoming disabled through damage to the umbilical cable.

Control through an umbilical was judged to be inconsistent with overall mission requirements. Signal loss through cables, higher power requirements than radio systems, large weight and volume of cable required on a small vehicle, cable susceptibility to wear and damage by following vehicles or enemy action, and determination of operator position by enemy observation were the main drawbacks in this determination. Inclusion of a cable connection option may be practical for limited uses. The only envisioned occasions where the cable is desirable are during periods of radio silence and when enemy jamming make use of a radio link unacceptable. The remaining choice is control by carrier wave signals.

All electromagnetic waves are "line-of-sight". In other words, the system becomes inoperative with a sufficiently large obstruction between the RPGV and controller which blocks the carrier wave. This limitation can be effectively removed by an airborne relay system consisting of a receiver, amplifier and transmitter (see figure next page). Signals are then transmitted through the relay system over obstructions. However, this seems to be an unnecessary complication of the RPGV detection system. Limiting the vehicle to "line-of-sight" operation does not seem to be a serious shortcoming. The vehicle could still operate several hundred meters to several kilometers in advance of the controller depending on flatness of the terrain and antenna height. Nevertheless, an airborne signal relay system is certainly a practical, though expensive, approach. The relay system could be mounted in an aircraft or suspended from a lighter than air balloon.

4.1.4.3 <u>Control Station Platform</u>.

The control station is that part of the system which is man operated. The vehicle will be monitored and controlled from a



STANDARD MFG. CO., INC.

DRAWING TITLE

POSSIBLE AIRBORNE SIGNAL RELAY SYSTEM

CODE IDENT NO	SIZE	DRAWING NO
98296	C	1

mobile console. The platform for transporting the control station can be:

A. Air vehicle

B. Ground vehicle

C. Man portable

An aircraft mounted control station is not consistent with overall mission requirements.

A. Mission time would be severely limited by aircraft fuel limitations.

B. An aircraft lingering in one area for a long period of time is an inviting target.

C. Unnecessarily complicates the system and does not offer any substantial advantage over the ground vehicle alternative.

The control station must contain at least the following elements:

A. Controls for vehicle operation

B. Controls for sensor operation

C. Sensor data displays

D. RF receiver and transmitter

E. Encoders and decoders

F. Microwave receiver

G. Amplifiers and relays

H. At least one and possibly two television monitors

I. If the control station is man portable, it must also contain its own power supply.

It is doubtful that the size and weight of the control station and battery packs could be low enough to allow classification of the station as "portable". At the very least, design of a portable station would be a formidable task requiring high technology state-of-the-art electronics. This is not consistent with the objectives of low cost, low risk, and high reliability/ maintainability.

The remaining alternative is mounting of the control station on an existing ground vehicle such as a jeep, truck or APC as the conditions dictate.

4.1.4.4 Summary; Basic Concepts and Criteria.

The remainder of the study will be developed around the previous conclusions which are summarized below.

A. The RPGV will be small, lightweight, lightly armored and highly maneuverable.

B. The system will use RF and microwave signals for two way transmission of data. The system will be limited to line-of-sight operation.

C. The control station will be a mobile device mounted in a separate ground vehicle.

4.2 Investigation of Selected System Concepts - Phase IV.

4.2.1 Investigation of Vehicle Parameters.

4.2.1.1 Chassis Design.

The first step in the vehicle investigation is analysis of the basic vehicle chassis type. An analysis of the major operational requirements related to the vehicle will be used as the approach to selecting the optimum design. It has already been determined that the vehicle should be as lightweight and small as possible. The other major operational criteria are:

A. Operation on adverse terrain

B. Maneuverability

4.2.1.1.1 <u>Adverse Terrain Operation</u>.

Since the vehicle is intended for off-route use, it must be capable of operation in adverse terrain and all types of soils. Meeting this operational parameter requires the following as a minimum.

A. On wheeled vehicles, all wheels must be driven. A vehicle with nonpowered wheels is not capable of operation in soft soils.

B. The vehicle must have a low ground pressure. This is essential for operation in soft soil, sand or mud.

C. The vehicle must have a high torque to weight ratio. This is particularly important when negotiating very rough terrain at low speeds or pulling through sand or mud.

D. Remote operation over rough terrain requires excellent stability. The vehicle center of gravity must be as low as possible and located as close to the wheelbase center as possible.

E. Even though the center of gravity must be low, the vehicle must still have high ground clearance. Low crossframe members or differentials can strike obstructions in rough terrain or "bottom out" when operating in soft soil or mud.

4.2.1.1.2 Maneuverability and Steering.

The vehicle must have excellent maneuverability. This is desirable in any all terrain vehicle but is particularly important in a remotely operated vehicle where the operator will probably be steering by a television monitor. Steering around obstacles could be a problem under these conditions unless the vehicle has a very short turning radius. Driving of the RPGV will be very different from the normal direct control of a vehicle. The human eyes provide a wide field of vision, effectively 180° with only minor head movements. Human eyes also have binocular vision which provides depth perception. This allows an operator of, for example, an automobile to plan his moves far in advance. This will not be true when steering from a television monitor with limited field of vision and no depth perception. The operator will be much less capable of advance planning and a vehicle with a long turning radius could be very difficult to effectively operate over rough terrain. This particular problem becomes critical when attempting to "worm" the vehicle through a minefield. In this respect, a very sharp turning radius is essential.

4.2.1.1.3 Chassis Types.

There are four basic chassis designs in common use. These are:

A. A rigid frame with steerable wheels.

B. A pivoted frame with fixed wheels.

C. Tracklayers.

D. Rigid frame and fixed wheels.

4.2.1.1.3.1 Rigid Frame, Steerable Wheels.

This is the familiar automotive type arrangement. The front wheels are normally steerable although, in some applications, both front and rear wheels are steerable to achieve a lower turning radius. This basic design can be applied to vehicles with two rear axles, in which case, only the front wheels are steerable and the turning radius becomes quite large. A minimum turning radius limits the vehicle to 4 wheels. The turning radius can be further reduced by making all four wheels steerable, but this results in a very complex vehicle. Cramp angle on steerable wheels are normally limited to 40° to 45°.

4.2.1.1.3.2 Pivoted Frame, Fixed Wheels.

This is the articulated vehicle common in certain types of construction machinery. In this design, the frame is pivoted at a point between the front and rear wheels. Steering of the vehicle is accomplished by turning the front half of the vehicle relative to the rear half. The advantage of the articulated vehicle is that it achieves the reduced turning radius of a four steerable wheeled vehicle without complex geometry and design. The articulated type vehicle has an inherent disadvantage in the area of stability. As the frame is pivoted, the distance from the vehicle center of gravity to the outside wheels is greatly reduced producing a drop in overall stability. This is particularly important when making downhill turns and considerable caution must be used to prevent overturning. Articulated machines are normally limited to four wheels and, because of the stability problem, the pivot angle is seldom over 45°.

4.2.1.1.3.3 Tracklayer.

A tracklayer is a vehicle like a tank. The undercarriage consists of a continuous steel linked belt (sometimes rubber) moving around a series of drive and idler sprockets and rollers. Steering is accomplished by producing a differential in speed between the right and left tracks. If sufficient power is available and with a properly designed transmission, one side can be driven forward and the other in reverse which results in the vehicle turning about its own center. This is the smallest possible turning radius for any vehicle. This type steering is commonly called "skid steering" and is employed on some modern tracklayers. Many tracklayers, particularly older types, do not have the power and proper transmission design to allow counter rotation of the tracks. In this case, steering is accomplished by locking one track and driving the other. The vehicle then turns about the center of the locked track. This is called "pivot steering".

Tracklayers are inherently very stable with a relatively low center of gravity. The very nature of the design places a large surface area in contact with the ground producing the lowest possible ground pressure. Tracklayers are capable of producing very large tractive forces and "spin out" of the tracks is unlikely on most terrains.

The advantages of tracklayers (maneuverability, stability, low ground pressure, and high drawbar pull) have made this concept very popular in certain types of off-road construction equipment. Tracks are also very common on high density machines, such as certain military vehicles. Military vehicles (tanks) often carry a considerable amount of armor plating. This results in a vehicle which is relatively heavy, compared with physical size. Tracks are sometimes chosen for this type vehicle because they have the capability of supporting large loads in less physical space than would be required by wheels. Tracks are also less vulnerable to damage from small arms fire than are wheels.

The use of tracks on certain types of military and industrial vehicles may be driven as much by tradition as operational requirements. The advancements in tire design, foam filling of tires, and new technology in wheeled vehicle design over the past decade is resulting in replacement of tracks with wheels in many applications. This is evidenced by the increasing number of military combat vehicles currently fielded or in development with wheeled undercarriage.

The reason for movement away from tracks in many applications is that tracks have several major inherent problems.

A. Relatively heavy construction

B. Relatively slow ground speed

C. Damaging to many types of surfaces

D. Low reliability and maintainability

E. High maintenance and logistics costs

F. Relatively short service life

G. High power requirements in turns

H. Low ground clearance

I. High noise and vibration level

J. High initial procurement costs

K. Poor survivability in abrasive soils such as sand or gravel

4.2.1.1.3.4 Rigid Frame - Fixed Wheels.

The fourth basic type of chassis design has a rigid frame and fixed wheels. Steering is accomplished by a differential in wheel speed (as in a tracklayer) and the vehicle is capable of turning about its own center. This concept has become increasing popular in the last few years because it has most of the advantages of tracklayers without many of the disadvantages. The concept is applicable to four or more wheels but is usually characterized by either six or eight wheels.

An example of a rigid frame, fixed wheel chassis is the "All Terrain Undercarriage" manufactured by Standard Manufacturing Company, Inc., Dallas, Texas (see next two pages). The "All Terrain Undercarriage" (ATU) contains either six or eight wheels all of which are powered. The ATU is manufactured in several different sizes for vehicles with a gross weight up to 100,000 pounds.

Since the rigid frame, fixed wheel chassis is a relatively new concept, the reader may not be familiar with the basic theory of a wheeled undercarriage. For this reason, a brief description of Standard's ATU will be given here. It should be noted that not all wheeled undercarriages contain all the features described for the ATU. There are other types which, for example, do not have the ability of counter-rotation and do not use the same type drive system. In addition, the lowered center wheel is a patented feature unique to the ATU.

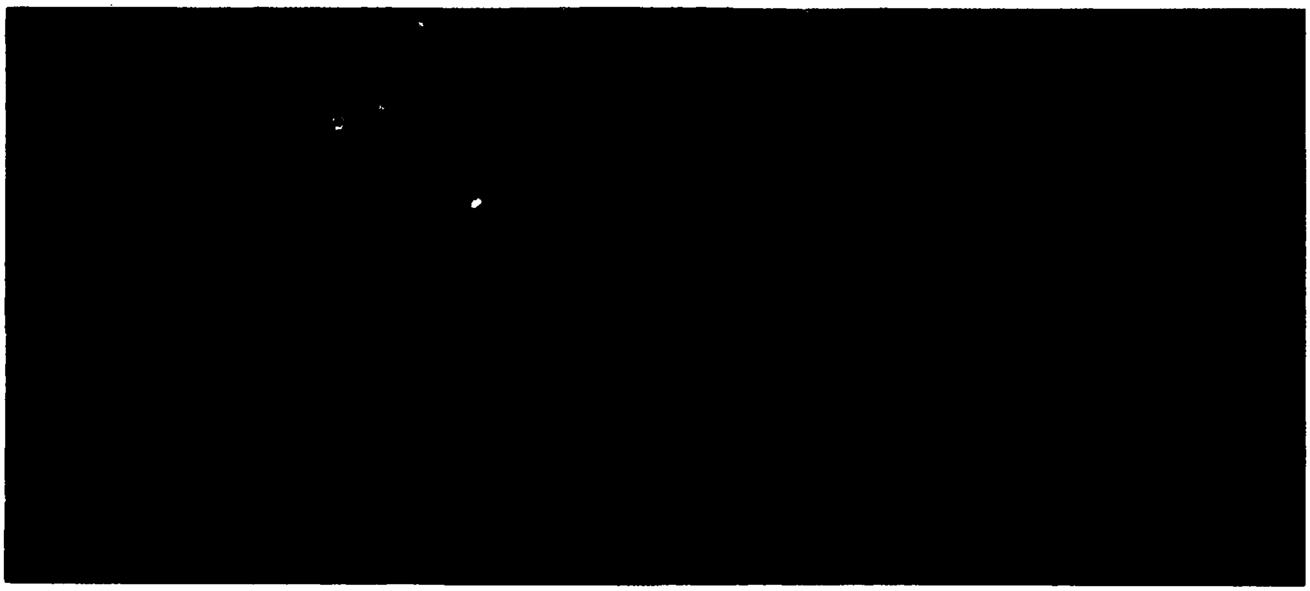
The basic ATU concept is an undercarriage made up of two side frame assemblies. These assemblies are identical; one is used on the left and one on the right side. Each side has three or more axles. (Herein, the discussion will deal with the three axle six wheel type.) The end axles are higher, relative to ground, than the center axle. This feature allows the center axle to carry a larger portion of the GVW than the end axles. The combination of the center axle carrying a greater load, plus the center wheels basically rolling in a circle when the vehicle is counter rotating, reduces the total skidding effect, particularly on hard surfaces. This feature reduces the turning resistance of the undercarriage, thus requiring less turning power. All three axles are jointly chain driven from a common gearbox (or boxes). This allows any wheel or combination of wheels to receive full drive power in the event one or more of the wheels on that side is off the ground. The gearbox is driven by a hydraulic motor coupled with a failsafe brake. The hydrostatic effect of the drive system is used as the normal service/working brake. The structural frame, each side, is an all welded tubular box section structure with integral axle supports. The drive chains, sprockets and axle bearings operate internal to this enclosed box section in an oil bath. The carried equipment supporting structure can be directly welded to these side frame structures or bolted to support pads.

The major features and their relating design criteria fall into two basic categories: drive system, and frame structure.

The 6-PAK All Terrain Undercarriage

The original "Standard" in the field for

STABILITY, MANEUVERABILITY, HIGH SPEED, LOW LIFE-CYCLE COST



TELEX 73326

STANDARD MANUFACTURING COMPANY INC. • 4012 W. Illinois Ave. • P.O. Box 210300 • Dallas, Texas 75211 • 214-337-8911 • Telex 73326

DRIVE SYSTEM - The drive system can be separated into two groups: 1) motor, brake, gearbox, chains and sprockets, and 2) tires, wheels, axles and axle bearings. Starting with an estimated GVW, a tire is selected on the basis that any pair of wheels must carry the total GVW. The theoretical turning resistance is determined first in that turning power dictates the maximum drive train torque requirements. The gearbox, motor, chains and sprockets are sized to provide an actual torque of 1.5 times greater than the theoretical turning resistance torque. In these determinations, certain trade-offs can be made with track width and wheel spacing which determine gearbox and chain sprocket ratios and chain size. For the minimum turning resistance possible, the track width is kept at a maximum and the wheel spacing at a minimum. The gearboxes are a combination of spur gear and planetary reduction elements. Virtually any type of drive motor (gear, vane, axial piston, etc.) or any make of drive motor can be used. High pressure two speed motors provide the widest torque and speed ranges.

Axle and axle bearing sizing is determined based on driving torque, chain pull and wheel loads. Tapered roller bearings are utilized as axle bearings and the bearing spacing is selected to optimize the axle and bearing size versus cost.

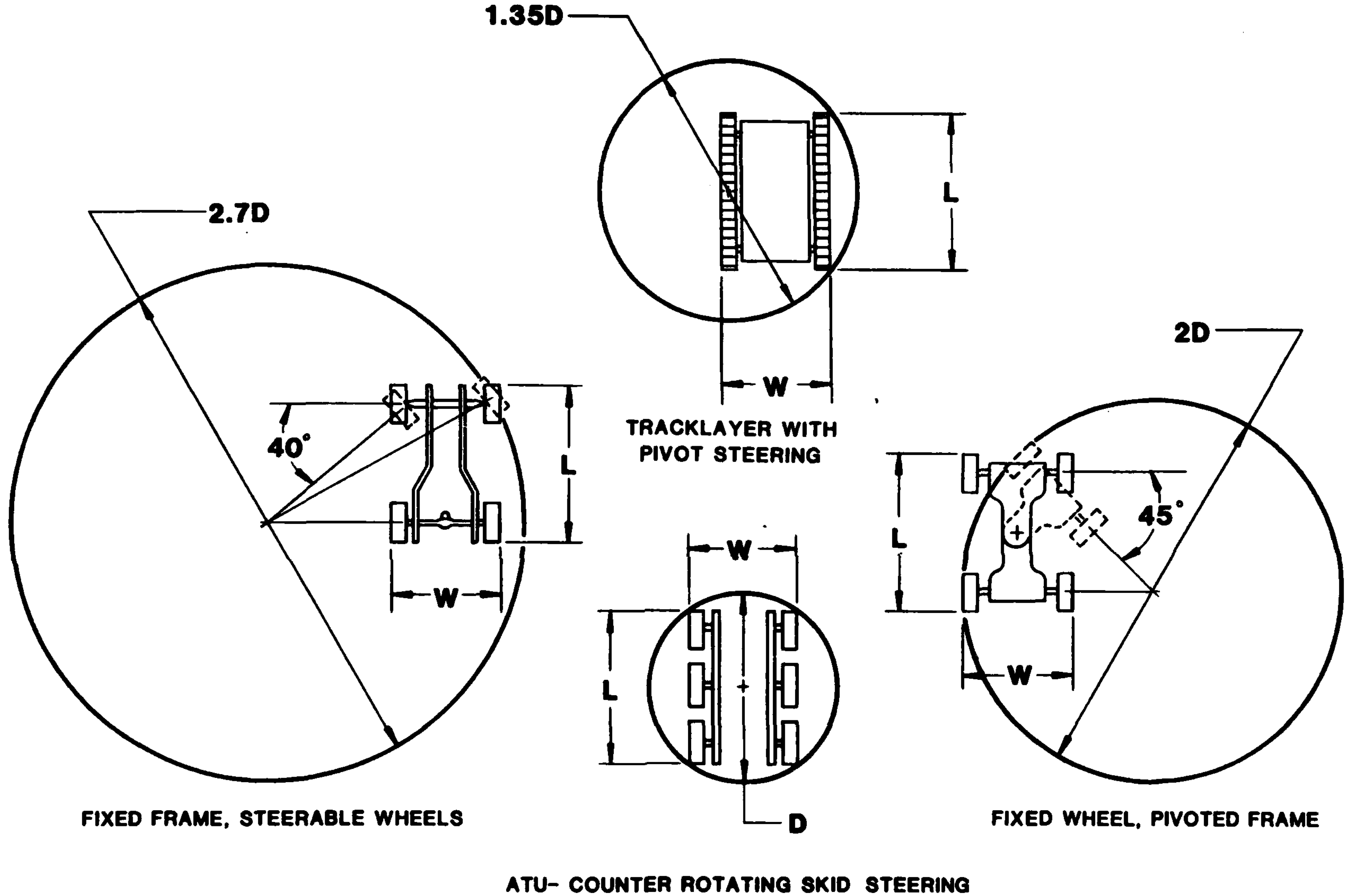
FRAME STRUCTURE - The main frame member, each side, is a tubular box section weldment. The basic box section size is determined by the chain and sprocket sizes. Strength, weight and cost factors are considered in the material sizing and type selection. Integral to this frame weldment are circular tubular elements which serve as the outboard axle bearing supports. The inboard bearings are contained in a bolt-on bearing carrier. This bolt-on bearing carrier also allows for the axle sprockets assembly/disassembly. Access openings are provided in the box section top plate for drive chain access. The box section side walls are reinforced to stiffen the walls and distribute the loads into the box structure at the axle and gearbox support points.

4.2.1.1.4 <u>Comparison: Wheel and Track Undercarriage</u>.

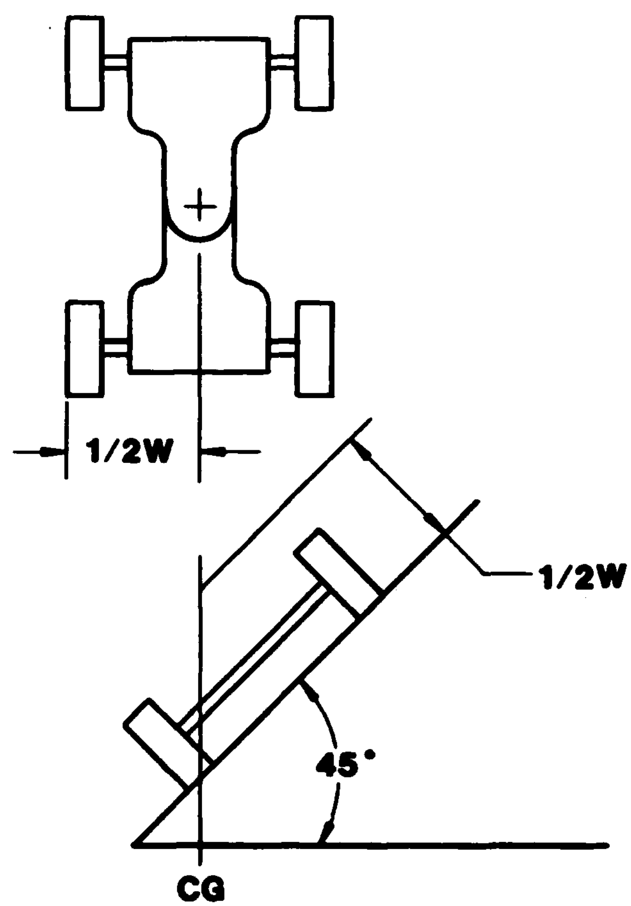
The basic requirements for operation in adverse terrain, low ground pressure, high tractive forces, excellent maneuverability, and good stability are not satisfied by the first two chassis concepts. A drawing showing the relative turning radius of the major chassis types follows on next page.

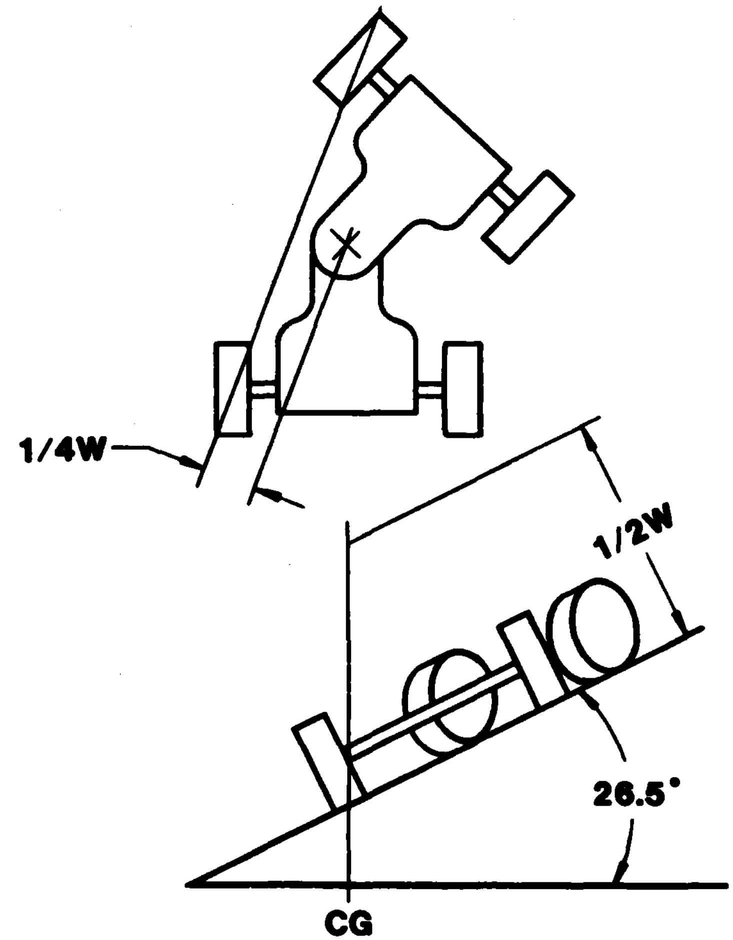
The fixed frame, steerable wheel concept (automotive type) would be limited to four wheels with two steerable wheels by practical considerations of cost and system complexity. This will result in a relatively high ground pressure and limit operation in soft soil. The turning radius will also be too large for effective negotiation of minefields.

The fixed wheel, pivoted frame concept (articulated type) is difficult to apply to small vehicles. This concept also has the same shortcomings as the automotive type. The ground pressure will be relatively high and the turning radius relatively large. In addition, there is the stability problem which is serious in a man operated vehicle and could be disastrous in a remotely controlled machine. A drawing showing the relative stability of the



STANDARD MFG. CO., INC.		
DRAWING TITLE: TURNING RADII OF BASIC CHASSIS DESIGNS		
CODE IDENT NO: 98296	SIZE: C	DRAWING NO: 2
SCALE: ~	WEIGHT	SHEET





STANDARD MFG. CO., INC.

ARTICULATED STEERING EFFECT ON CROSS SLOPE STABILITY

98296	C	3

vehicle with and without the frame pivoted demonstrates this problem. The stability in a maximum turn is reduced by a factor of about 2.

The remaining two chassis concepts (tracklayer and rigid frame, fixed wheel) both comply with the basic requirements. An additional advantage of these two chassis types is simplicity of controls. Skid steering is basic to these two concepts. This means, in effect, that the same system used for propelling the vehicle is also used for steering. This is obviously superior from a control standpoint.

All things considered, both the tracklayer and ATU concept are about equal with respect to ground pressure, tractive forces, maneuverability and stability in this particular application. Therefore, determination of the optimum concept requires a deeper analysis of other factors and requirements. The following characteristics and requirements will be evaluated with respect to relative merits of the two concepts.

A. Weight

B. Ground speed

C. Simplicity of concept, reliability and maintainability

D. Life cycle cost

E. Survivability

F. Ground clearance

G. Noise and vibration

4.2.1.1.4.1 <u>Weight</u>.

A track undercarriage will commonly weigh about twice as much as a wheel undercarriage of the same capacity. This follows from the all steel construction and necessity for a number of track rollers, drive sprockets and the relatively heavy track itself. The undercarriage will usually account for 30 to 40 percent of a tracklayer's total weight. Conversely, a wheel undercarriage will comprise only 15 to 20% of the total vehicle weight.

4.2.1.1.4.2 Ground Speed.

The nature of the construction and design places a low limit on practical ground speed for a tracklayer. Industrial track undercarriage construction equipment commonly has a maximum ground speed of 2 to 3 miles per hour. This is forced by the nature of the track design. Each link joint contains an unlubricated pin and bushing. The tracks are driven by steel sprockets rolling over the link pin bushings. These are high wear points and have practical limiting speeds to prevent unacceptably rapid wearout. In addition, the track rollers are subject to damage from dynamic forces. Rough terrain operation can cause concentration of weight on one roller resulting in damage to the roller, link, and track shoe. This problem is greatly accentuated by an increase in ground speeds because of induced dynamic loads. It must be noted that industrial tracklayers do not have any type of suspension system. There is no cushioning or shock absorption when hitting or rolling over an object. Hitting a football size rock at high speed will seriously damage or disable a track. From this standpoint, tracks are not nearly as "rugged" as they appear.

Low ground speed is inherent in the track concept and, it must be stressed, is a very real problem without a practical solution. The tracklayer industry has attempted for many years to produce a practical reliable, cost effective high speed track design. The failure of these efforts is evidenced by the total absence of a commercially available high speed tracklayer.

A wheeled undercarriage is capable of ground speeds up to about 20 miles per hour without a suspension system. Speeds in excess of 20 mph require a suspension system because of induced dynamic forces. The wheeled undercarriage is capable of relatively high speeds because only the tires are in contact with the ground and the wheels are mounted on axles supported by lubricated live bearings. The tires also provide a natural cushion which dampens dynamic loads.

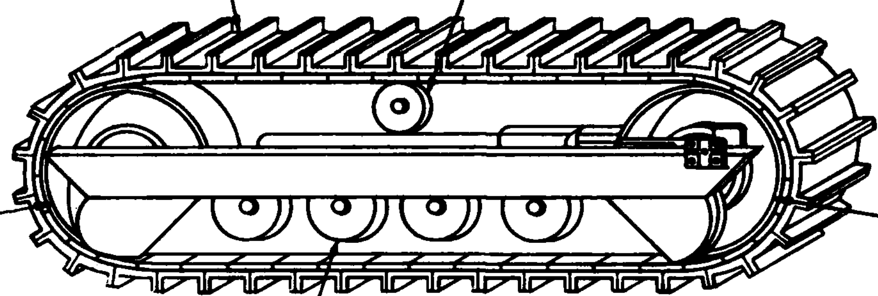
The author has somewhat belabored low ground speed of tracklayers. However, the point has been the practicality of high speed tracks, not the technical possibility. Obviously, there are numerous military tracklayers with the capability of ground speeds in excess of 30 mph over rough terrain. This capability has been achieved by incorporation of a very elaborate and expensive suspension system and acceptance of high cost, short service life and low reliability as a "necessary evil". These trade-offs are probably justified in a battle tank. However, they are extremely difficult to justify in anything else. The advantage of high speed is more than offset by the extreme disadvantages in practically all other applications. The concept of high speed tracks is judged not compatible with the basic concept of the

RPGV mine detection system. Therefore, an RPGV with track undercarriage would be limited to a maximum ground speed of about 2 to 4 miles per hour.

4.2.1.1.4.3 Simplicity of Concept; Reliability and Maintainability.

A typical track design is shown on the following drawing. It will be assumed that the reader is familiar with the track concept and only a brief summary of the design will be given here. The description is also limited to industrial type tracks. High speed military tracks are quite different and have already been eliminated as a practical consideration for the RPGV.

The track itself is a continuous steel linked belt passing around a drive sprocket and idler sprocket. The arrangement is somewhat similar to a bicycle chain and sprockets. The number of individual links in the track depends on the track length, sprocket pitch and other variables but is normally in the range of 50 to over 100 links. Like a bicycle chain, the links are pinned together to enable bending around the drive and idler sprockets. The idler sprocket is normally mounted on a device intended to maintain tension on the track. This is extremely important since loss of track tension will result in "throwing" of a track and possible extensive damage. Between the drive and idler sprockets are a number of rollers which distribute the vehicle weight along the track. The number of rollers required is again variable but is usually in the range of 2 to 6. There will also be a number of idler rollers whose function is to support the track on the unloaded (top) side.



STANDARD MFG. CO., INC.		
TYPICAL TRACK DESIGN		
98296	C	4

The complexity of this concept is apparent. It contains a large number of unlubricated moving parts and pivot points and the sprockets and rollers are operating steel against steel. The detrimental effects are compounded by the fact that all this movement is taking place right down in the dirt. Tracks are very susceptible to damage from foreign objects jammed between the links or between the track and rollers. Abrasive soils such as sand or gravel greatly increase the wear on sprockets, link pins and bushings. The reliability of tracks is comparatively low. This is a consequence of the large number of moving parts, large number of unlubricated joints and the fact that the link pins, bushings, sprockets, and rollers are exposed to abrasive effects of the soil.

The reliability of a system is directly proportional to the number of active elements in the system. In other words, the greater the number of parts, the lower the reliability. For a given system, minor increases in reliability can be achieved through design improvements and better quality control. A substantial increase in reliability will almost always require a drastic alteration of the concept which results in either a large decrease in functional element numbers or eliminates some operational parameter which is driving (forcing) the low reliability. The reliability of a track is essentially determined by the large number of components and the abrasive and damaging effects of the terrain. It is not realistic to expect any substantial improvement in the reliability of tracks in a new design. Low reliability is, in effect, inherent in the very operational and design concept.

Preventative and corrective maintenance is high for tracks. The high corrective maintenance labor is a direct consequence of the low reliability. The repair or replacement of track shoes, links, pins and bushings will be a frequent requirement, particularly in highly abrasive soils. Preventative maintenance is also high for tracks and must be performed on a daily basis. This includes:

A. Cleaning of track links and rollers

B. Greasing and oiling rollers and sprockets

C. Checking and adjustment of track tension

A wheeled undercarriage, properly designed, will have 4 to 5 times the reliability of a tracked undercarriage. This is a direct result of three important advantages in the wheel concept.

A. The only thing in contact with the ground is the wheels (tires).

B. The drive mechanism can be entirely enclosed and effectively lubricated.

C. The wheel concept has about 1/3 to 1/2 the number of functional elements of a track.

Corrective maintenance will be low because of the high reliability. Preventative maintenance can be virtually eliminated (compared with tracks) if the entire drive mechanism is enclosed.

4.2.1.1.4.4 <u>Life Cycle Cost</u>.

There are numerous factors which determine the total cost of a vehicle over its useful life. For the purpose of comparing the life cycle cost of track and wheel undercarriages, we shall use:

A. Initial procurement cost

B. Cost of replacement parts

C. Cost of corrective maintenance labor

D. Cost of preventative maintenance labor

Experience has demonstrated that about 90 to 95 percent of the life cycle cost will be determined by these four factors. A service life of 15 years and a utilization rate of 4 hours per day, 5 days a week will be used. Of course, in wartime, the utilization rate will be much higher, but it is not reasonable to base a 15 year cost analysis on wartime conditions. The cost analysis also assumes constant dollars, i.e., zero inflation.

The initial procurement cost of a wheeled undercarriage is about 70 to 75 percent of a track undercarriage. A track undercarriage in the size required for the RPGV would cost approximately \$10,000.00 making the wheeled undercarriage cost about \$7500.00.

The assumed utilization rate equals about 16,000 operating hours over the life of the vehicle. In this length of time, it is estimated that the replacement parts costs for a tracked undercarriage will equal four times the initial procurement cost or about \$40,000.00. Because of the higher reliability and improved operating conditions for the wheeled undercarriage, replacement parts will just about equal the initial cost. However, tire wearout may play a more important role in life cycle cost than would be indicated by a simple reliability analysis. A cost factor of two times the initial procurement cost is probably more realistic. Replacement parts for the wheeled undercarriage will cost about \$15,000.00 over the service life.

Corrective maintenance on a track undercarriage will equal about 20% of the operating hours. For the 16,000 service life operating hours, about 3200 manhours of corrective maintenance will be required. The latest figures available to the author for the cost of labor for military personnel in this category is about $7.00 per hour making the life cycle maintenance cost equal $22,400.00. Corrective maintenance on the wheeled undercarriage will be about 5% of the operating hours. This is a direct consequence of the improved reliability. This makes the life cycle corrective maintenance cost $5600.00.

Preventative maintenance cost for a track undercarriage is estimated at one manhour for each 10 operating hours. Over the life of the vehicle, 1600 manhours will be expended on preventative maintenance at a cost of $11,200.00. The wheeled undercarriage, because of the enclosed and lubricated drive system and the elimination of cleaning and tension adjustments, requires only one hour of preventative maintenance per each 50 operational hours. This equals 320 manhours at a cost of $2240.00.

The life cycle costs for the two systems is the summation of the four elements.

	Tracks	Wheeled
Initial Cost	$10,000.00	$ 7,500.00
Replacement Parts	$40,000.00	$15,000.00
Corrective Maintenance	$22,400.00	$ 5,600.00
Preventative Maintenance	$11,200.00	$ 2,240.00
Life Cycle Cost	$83,600.00	$30,340.00
Undercarriage Cost per Year	$5,573.00	$ 2,023.00

Of course, these estimates are somewhat subjective and subject to critical review. Nevertheless, the life cycle cost differential is so great that there is no doubt the wheeled undercarriage is very attractive with respect to cost.

4.2.1.1.4.5 Survivability.

There are two categories of survivability; combat and environmental/operational. Operational survivability has already been discussed to some degree. Generally speaking, the wheeled undercarriage has the advantage in this area. Almost all types of soil and terrain are detrimental to operation of tracks. By comparison, the type of terrain has almost no effect on the operational survivability of the wheeled undercarriage.

Combat survivability is a more difficult problem to analyze. Intuitively, it may seem that tracks have the advantage in this area. Certainly, they are more resistive to small arms fire than is a normal tire and probably more resistive to an AP mine explosion. (Note: Antitank mines are eliminated from this discussion since both types of undercarriage would be destroyed or disabled by an AT mine explosion.) We use the word "probably" with respect to AP mines because we are discussing a small vehicle and, therefore, lightweight tracks. It is not certain that lightweight tracks would survive an AP mine. On the other hand, a six wheeled undercarriage probably could survive such an explosion. The reason is that, even with one wheel completely destroyed, the wheeled vehicle would still be capable of operation although some capabilities would be reduced. Loss of a track, of course, completely immobilizes a tracklayer. The AP mine survivability of wheels and the type of small, lightweight tracks which would be used on the RPGV is judged about equal. If the tires were "foam filled", the tire has a very good possibility of survival and, in this case, may be superior to a lightweight track.

Survivability of wheels with respect to small arms fire requires that the tires be filled with one of the several types of "foam" currently used in many off-the-road industrial vehicles. This foam (normally a urethane) is pumped into the tire under pressure entirely replacing the air in the casing. When the liquid cures, it becomes a solid, resilient urethane rubber which effectively eliminates loss of a tire from punctures or cuts smaller than about 4 inches in length. The foam filled tire becomes heavier and harder than an air filled tire. However, it does not become a "hard rubber" tire. In fact, a foam filled tire maintains most of the shock absorption capability of a pneumatic tire. The weight increase, in a tire size applicable to the RPGV, would be 60 to 70 pounds per tire.

The survivability of foam filled tires with respect to small arms fire and direct contact AP mine explosions has been tested by the U.S. Army at Aberdeen, Maryland. Foam filled tires are relatively immune from the effects of sniper fire. The tire can withstand numerous "hits" and still function normally. On the other hand, the capability or probability of surviving sustained or concentrated small arms fire is probably better in a tracklayer. Once again the word "probably" is used because the effects of small arms fire on lightweight tracks is not known for certain. It is conceivable that foam filled tires could be more effective against concentrated small arms fire than lightweight tracks.

The survivability relating to direct contact AP mine explosions is best demonstrated by the following four photographs.

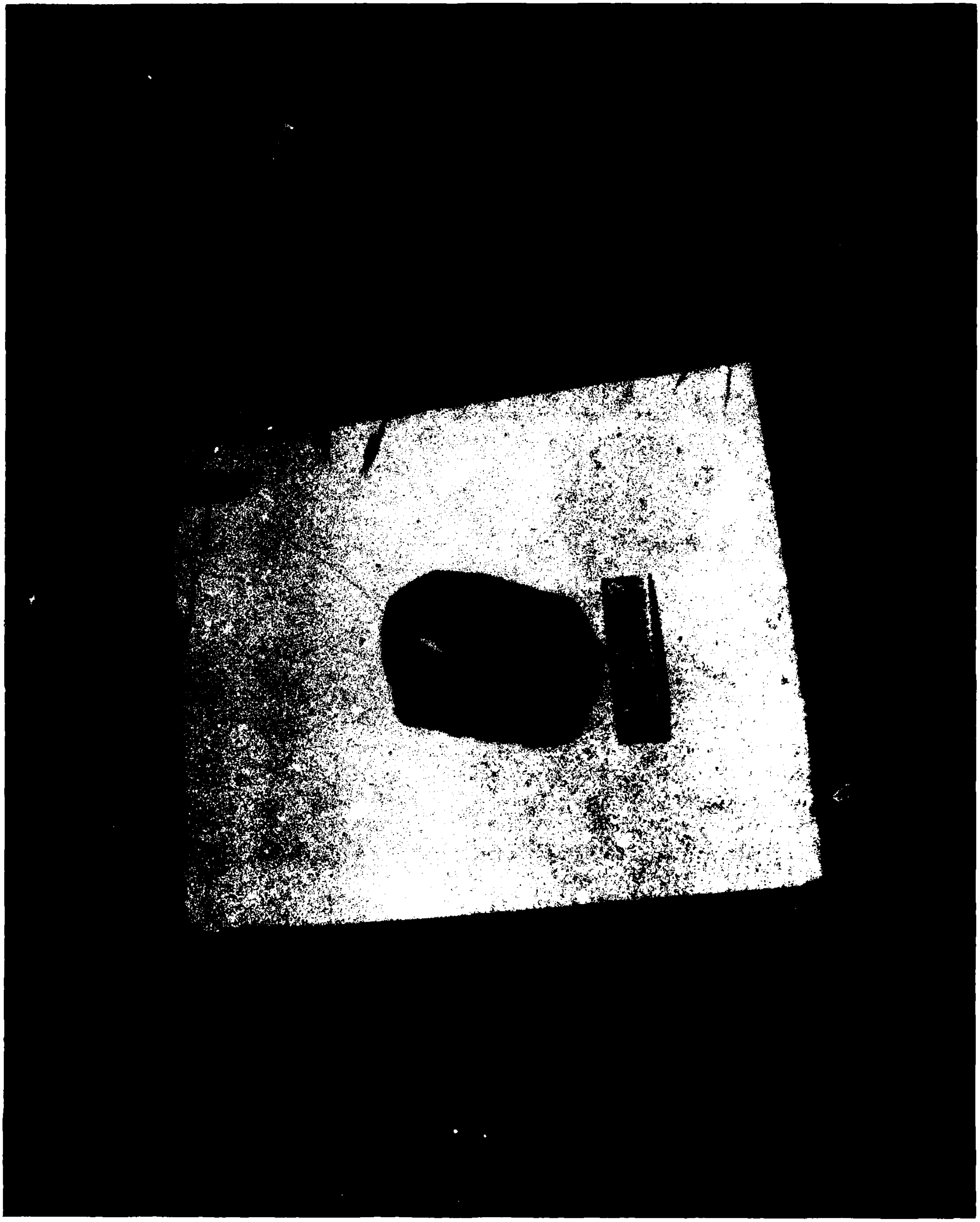
A. Photograph No. 1. The explosive charge used in these tests was a bomblet from an Air Force cluster bomb weapon.

B. Photograph No. 2. This photograph shows damage to an ordinary (foam filled) 7.50-16 tire and wheel. Note that both tire and wheel have been effectively disabled.

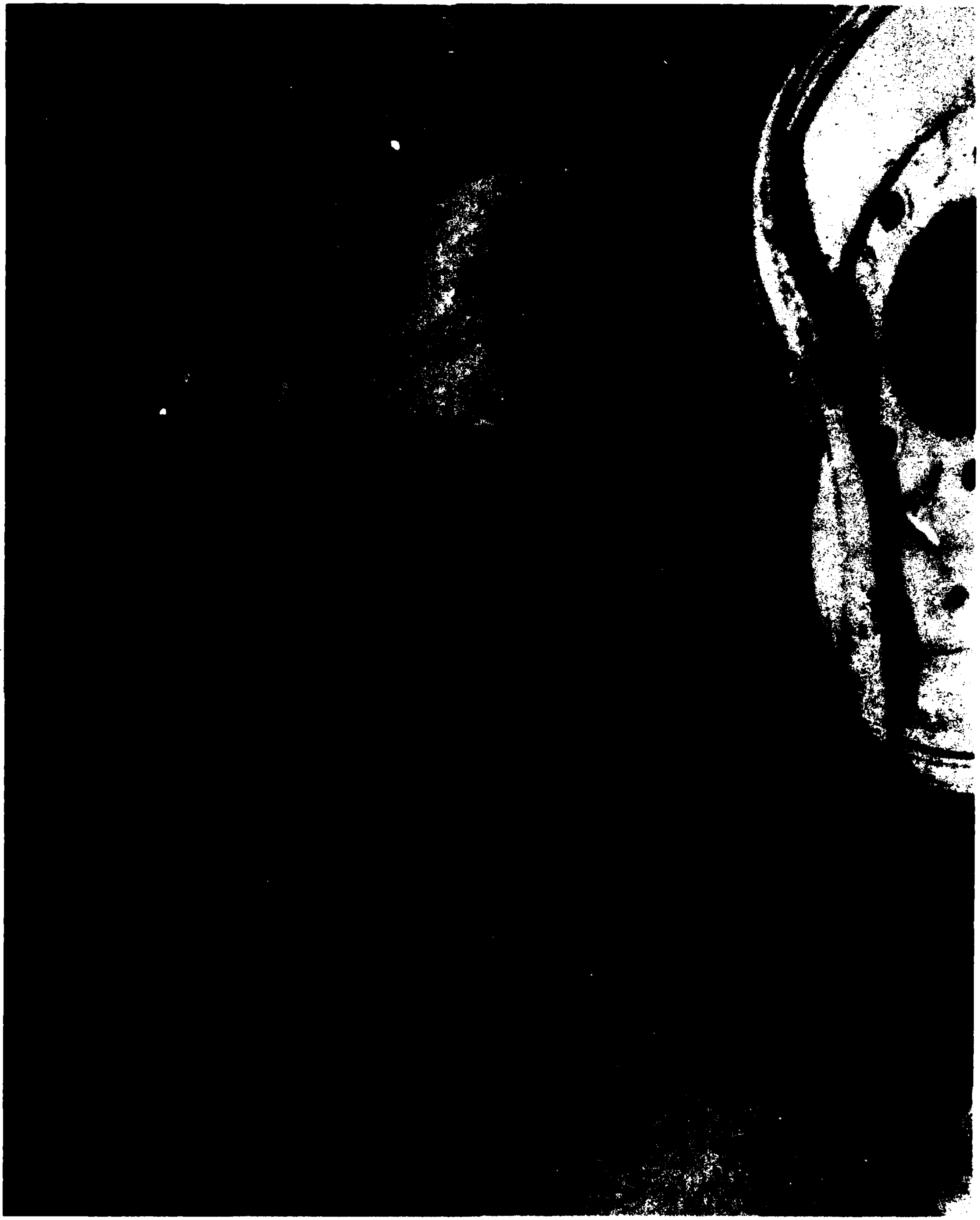
C. Photograph No. 3. Damage to a 18-19.5 off-road tire, foam filled. Although the tire has been seriously damaged, it has not been disabled. A vehicle equipped with this foam filled tire would still be capable of normal operation.

D. Photograph No. 4. Damage to a large diameter earthmover tire (23.5-25). Damage has been minimal. Test personnel estimated that two additional explosions at the same point would be required to disable the tire.

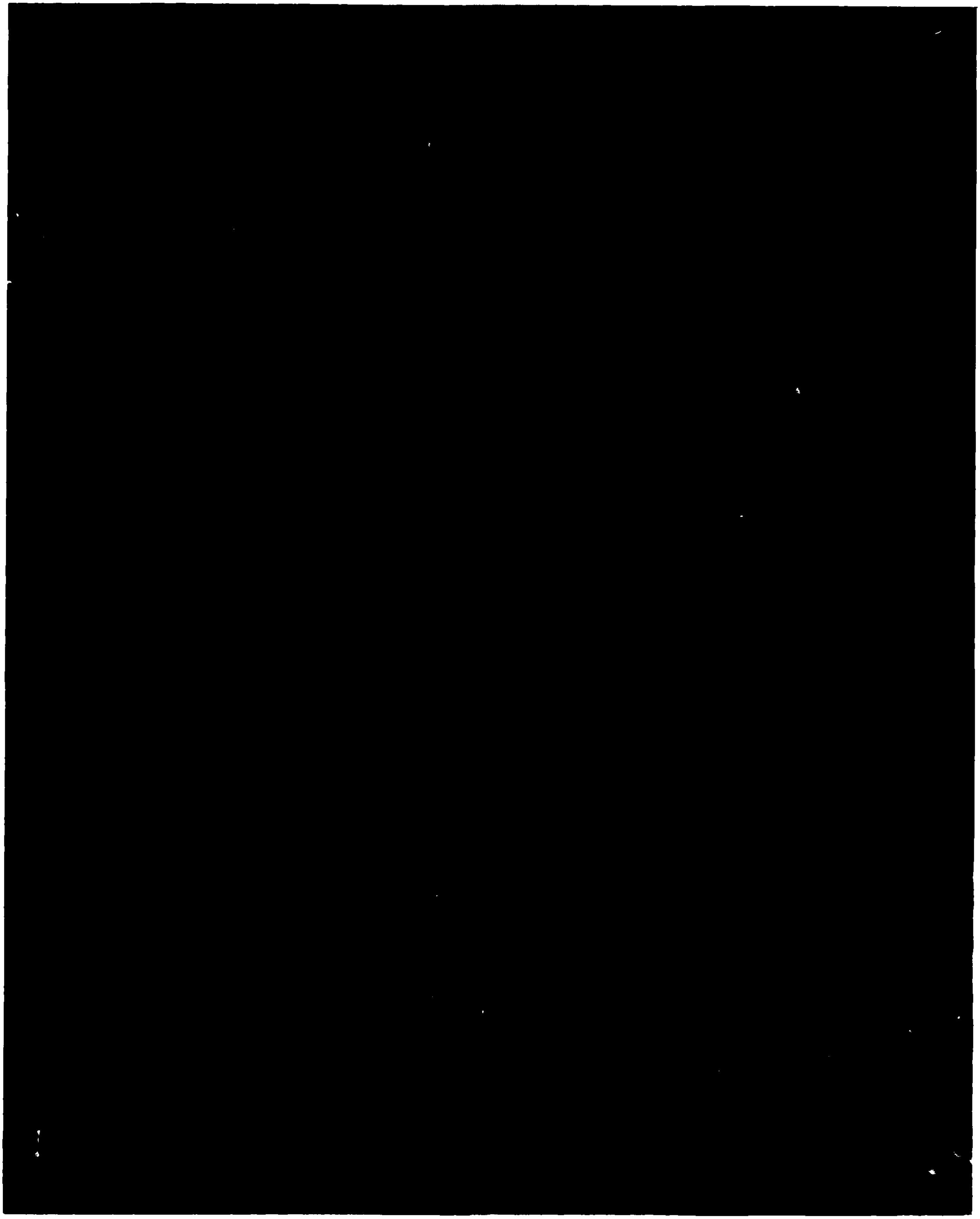
The Aberdeen tests have only recently been completed and the official test results will not be published for several months. We cannot, therefore, refer to a specific report number or official results or conclusions. The photographs must stand on their own merits and the reader draw his own conclusions and results from them. However, there are three interesting points which should be noted.



PHOTOGRAPH NO. 1
BOMBLET



PHOTOGRAPH NO. 2
7.50-16 TIRE



PHOTOGRAPH NO. 3
18-19.5 TIRE

PHOTOGRAPH NO. 4
EARTHMOVER TIRE

A. The bigger the tire, the greater the probability of survival. This, of course, seems to be intuitively correct.

B. Tire diameter is not as important as section height and width. The resiliency of the tire is determined by section width and height. It is this resiliency which absorbs the explosion and prevents damage to the wheel.

C. Since a track, by nature, does not have resiliency like a tire, it is doubtful that a lightweight track could dissipate the explosion and still be capable of operation.

4.2.1.1.4.6 Ground Clearance.

One of the primary advantages of tracks is their relatively low profile. This also results in one of a tracklayer's primary disadvantages, low ground clearance. The ground clearance of a wheel undercarriage will be about 50% greater than a corresponding size track undercarriage. The reason for this difference is the requirements for cross axles and torsion bars on tracked undercarriages. The maximum height for these cross members is the center of the drive or road wheels to which they are attached. On a wheeled ATU, however, the only items of equipment required to be between the wheels are the two thin side frame members and their respective hydrostatic drive motors. Frequently, the lowest member spanning the gap between side frames is at a level near the top of the wheels. Comparison of similar units having thirty inch diameter wheels or sprockets would result in the tracked undercarriage having a nominal clearance of approximately thirteen inches. The wheeled ATU would have a clearance of approximately twenty-five inches in the center, sixteen inches under the drive motors, and nine inches under the side frame members. This comparison readily shows that the wheeled ATU can be made to straddle obstacles approximately twice as high as its tracked counterpart.

4.2.1.1.4.7 Noise and Vibration.

The noise and vibration produced by a tracklayer is well known. Everyone has watched a tank or bulldozer roll by and noted the high noise level and characteristic "bump-bump" motion of the tracks almost like it was rolling over a series of invisible objects. This characteristic of tracklayers is a consequence of the difference in angular velocity between the drive sprocket pitch line and the track shoes. As each track shoe contacts the ground, it must rapidly decelerate to match the sprocket velocity. The dynamic force of this deceleration produces the "bump". These dynamic forces also make a tracklayer self destructive, to a degree, since they are transmitted through the shoes to the links, pins, bushings, and sprockets.

The inherent noise and vibration produced by a track would be a serious disadvantage in the RPGV mine detection system. The electronics of the television system and camera, and the mine sensors and detectors would require an extra degree of sophistication and protection to enable effective operation on a tracked vehicle. The shock and vibration transmitted to the carried equipment is one of the most serious problems with a tracklayer.

4.2.1.1.5 Summary - Chassis Design.

The analysis has reached two basic conclusions.

A. The undercarriage of the RPGV must be either track or rigid frame, fixed wheeled (six or eight wheels).

B. The wheel undercarriage, such as the Standard Manufacturing Company, Inc. ATU, is the most advantageous approach in this application. Tracks may possibly offer better survivability against small arms fire, but the wheeled undercarriage is superior in every other operational requirement.

The conclusions of this analysis are so overwhelmingly in favor of a wheeled concept as to appear prejudiced. However, the investigators believe the analysis has been fair and realistic. The fact of the matter is, tracks offer few, if any, advantages over wheels except in extreme circumstances while tracks suffer from a number of very serious inherent problems. A reasonable question is: "If tracks are so bad, why are there so many tracklayers around?" This is a fair question and it has two answers.

A. The use of tracks in certain applications is strongly traditional. It is difficult or impossible to convince some users that anything but tracks will work in certain applications. However, wheeled undercarriages are starting to make strong headway in applications previously the sole domain of tracks because the advantages of wheels are so numerous.

B. Tracks are the proper choice for an undercarriage in certain applications where a particular operational parameter favorable to tracks is an all important and overriding consideration. Two examples of such applications come to mind.

(1) Battle tank. In a battle tank, low profile, the inclusion of many tons of armor on a relatively small frame size and maximum survivability makes the use of wheels impractical.

(2) Bulldozer. The primary requirement for a bulldozer is enormous drawbar pull and as close to 100% efficiency in utilization of vehicle weight in pushing/pulling as possible. Wheels and tires cannot compete with tracks in this type application.

It must be noted that no such parameters are of such overriding importance in the RPGV as to justify use of tracks.

4.2.1.2 Transmission Design.

The transmission (as used herein) is that component or group of components which transmits power from the engine to the final drive. The transmission will normally contain, at least, a method of changing the engine to final drive speed/torque ratio and a method of reversing the direction of final drive rotation. There are basically two types of transmissions, mechanical and hydrostatic.

There are numerous types, styles, and configurations for a mechanical transmission. As used on a tracklayer or wheeled, skid steered machine, it will normally consist of a multi-speed gearbox and clutch/brake arrangement at each track drive. The clutch/brake allows locking of one side while driving the other side to provide steering. This is the most common arrangement on older tracklayers and other type skid steered machines. High speed tracklayers will usually have a much more sophisticated design for the transmission system. These systems will not be discussed since it has been determined that high speed tracks are not applicable to the RPGV.

Mechanical transmissions have two major advantages over hydrostatic transmission.

A. They are capable of much higher operating speeds. A practical and reliable high speed hydrostatic transmission has not been developed although much work is being done in this area. Hydrostatic transmissions are usually limited to a ground speed of about 20 mph.

B. Mechanical transmissions operate at a much higher efficiency than hydrostatic transmissions. Typically, a mechanical transmission operates in the 85% to 95% efficiency range compared with 75% to 85% for a hydrostatic transmission.

Mechanical transmissions have become almost obsolete in certain types of off-road, low speed vehicles such as agricultural and construction machinery. In low speed equipment, the mechanical transmission loses its first advantage. As to the second advantage, there are two ways of looking at efficiency. The classical efficiency is simply "work in" versus useful "work out".

From this viewpoint, mechanical transmissions are superior. Another type of efficiency is the capability of converting engine power to final drive torque. From this viewpoint, hydrostatic transmissions are the better choice. In fact, they are so much better at utilizing engine power to produce torque that the penalty in classical efficiency becomes relatively unimportant in many off-road vehicle applications. Practical and reliable hydrostatic transmissions are a relatively new development (10 to 15 years), but the advantages for low speed, off-road vehicles are so great that they have almost obsoleted mechanical transmissions in these applications.

In a mechanical transmission, speed and torque are directly proportional. The torque delivered at the final drive is equal to maximum engine torque multiplied by a certain gear ratio. The gear ratio is variable to allow selecting the optimum combination of speed/torque. In an automobile, this can be accomplished with only 2 or 3 gear ratios. In a large truck, it may require 10 to 15 gear ratios. However, no matter how many gear ratios are available, speed and torque are still directly related. Developing maximum torque at all speeds would require an infinite number of gear ratios.

A hydrostatic transmission produces the effect of an infinite number of gear ratios. This is a consequence of the characteristics of hydraulic pumps and motors. The torque output of a hydraulic motor is independent of speed. For a given operating pressure, the motor will produce the same torque at all speeds (within the limitations of engine power). As the pressure increases, so does the output torque independent of the motor speed. A hydraulic pump is a fluid transfer device and its purpose is to move fluid from one point to another. The pressure produced by the pump is simply equal to what is required to move the fluid. If there is a high resistance to fluid flow, the pump will produce a high pressure. Conversely, if the resistance is low, the pressure will be low. A hydraulic pump will always continuously and automatically adjust its pressure to exactly what is required to continue the fluid transfer. If a pump and motor are connected, these two characteristics together produce a hydrostatic transmission. If the motor is connected to a vehicle drive wheels, then the ground speed of the vehicle is determined by the speed of rotation of the motor. As resistance to this rotation increases, the pump automatically increases pressure, as required, to maintain the same rotational speed. Thus, at every vehicle speed, the full engine power can be delivered at the drive wheels. This is very desirable in an off-road, rough terrain vehicle.

A properly designed hydrostatic transmission also has three other major advantages.

A. Flexibility in design and arrangement of the drive system. The only connection between the engine and final drive are flexible hydraulic lines.

B. Simplicity of controls is provided by running the engine at a fixed constant speed, elimination of the need to "shift gears", and combining drive, steering and braking into one set of controls.

C. Hydrostatic transmissions provide for counter rotation of the drive wheels turning the vehicle about its own center. This is not easily achieved with mechanical transmissions.

A hydrostatic transmission which might be used in the RPGV is described in the following paragraphs. The same theory is applicable to both tracked and wheeled undercarriages, large and small vehicles.

The engine is used to drive two hydrostatic pumps which convert the engine torque and speed into hydraulic pressure and flow. Flow is transferred out of the pumps by large high pressure hoses which go directly to the hydrostatic motors. At the hydrostatic motors, pressure and flow is converted back to torque and speed. The torque output of the motor is then multiplied by use of a planetary gear reduction. The type of pumps and motors used are generally the axial piston variable displacement type and operate at pressures from zero to 5000 psi maximum. The type of hydraulic circuit utilized is generally a closed loop circuit aided by a charge pump to keep the circuit completely filled with hydraulic fluid at all times. This type of circuitry reduces the continuous horsepower requirements needed for operating at anything less than the maximum flow and pressure available. Control for the undercarriage is achieved by independently controlling the output volume of the pumps. There are two pumps, each of which is independently connected to one of the two drive motors. Therefore, controlling one pump controls one side frame of the undercarriage and controlling the other pump controls the other side frame of the undercarriage. The pumps are designed with a movable swash plate which, when varied or moved, varies the amount of flow coming from the pump and going to the motor thereby controlling the speed of the motor. This flow can also be reversed to cause a reversal of direction in the motor. By controlling the swash plate angle in the pumps, the speed and direction of the undercarriage can also be controlled. If one motor is driven faster than the other motor, a turn will result. If one motor is driven in an opposite direction from the other motor, a turn about center can be accomplished. All turns of any radius can be accomplished by controlling direction and speed of each side of the undercarriage.

There is normally a speed shift available in the variable displacement motors. This speed change is achieved by the destroking of the swash plate in the hydraulic motors. This reduces the displacement of the motors and, therefore, increases the output speed of the motor shaft while maintaining a constant flow requirement from the pump. This speed change is normally about a 2 to 1 ratio between low range and high range in the motor.

A characteristic of a properly designed hydrostatic transmission is that, when the vehicle is in motion either forward or reverse and the pump swash plates are allowed to return to center or are moved to center by the operator's control, the unit comes to a quick stop due to a hydraulic characteristic in the system called hydrostatic braking. This means that the motor has momentarily taken over the role of the pump and the pump has momentarily taken over the role of the motor since the flow coming out of the pump was not sufficient to maintain the motor at the speed at which it was previously running. The motor tries to retain its speed but, to do so, it must pump oil through the closed loop system into the pump and speed the pump up enough to make up for the difference in the displacement that the pump has now taken. The amount of torque required by the motor to cause it to pump the oil back through the pump is extremely high due to the fact that all the oil pumped will be at the maximum relief pressure. This gives the unit an effective brake and is actually capable of skidding the tires on dry pavement. This hydrostatic braking is normally used for the service brake on the vehicle.

4.2.1.2.1 Summary - Transmission.

A hydrostatic transmission is ideal for the RPGV. In the first place, the inherent advantages which have made hydrostatic transmissions so popular in other low speed, rough terrain vehicles are equally applicable to the RPGV. In the second place, the simplicity of controls is a big advantage in a remotely controlled vehicle. Driving, steering, vehicle speed, and service braking are all accomplished by controlling displacement of the two pumps. All that is required for control of pump displacement is one electrically operated proportional control valve at each pump. This is a significant advantage in cost effectiveness and man/machine interface.

4.2.1.3 Power Plant.

The RPGV must have a source of power. There are three methods available.

A. Electric motor

B. Internal combustion engine

C. Turbine

An electric motor has the advantage of simplicity, high reliability and extreme quietness. A wheeled vehicle powered by an electric motor could be made inaudible at distances greater than about 100 feet. Unfortunately, these advantages are more than offset by the need to periodically recharge the batteries. This is judged to be so undesirable that further consideration will not be given to an electric motor. In any event, if an electric motor was considered, the vehicle would need to be very small and lightweight because of the limitations on availability and size of batteries and DC traction motors.

A gas turbine packs considerable power into a small space, but several drawbacks remove it from consideration. First, hydraulic pumps operate at much lower rpm than a turbine requiring gear reductions which decrease efficiency and cost space. Second, operator maintenance is much more technical than internal combustion engines. Third, the heat from the turbine exhaust may be sufficient to activate sensors on heat seeking missiles as is the case on the M1 tank.

The remaining alternative is an internal combustion engine of which there are basically two types, gasoline and diesel. Each type has advantages in specific applications.

Gasoline Engine

A. Gasoline engines typically cost 1/2 to 1/3 as much as a diesel engine of the same horsepower.

B. Gasoline engines will weigh 1/2 to 2/3 as much as a comparable diesel.

C. Gasoline engines are quieter than diesel engines by as much as 5 to 8 decibels on the "A" scale at 50 feet. They also produce a lower level of vibration.

D. Gasoline engines are more responsive and better able to cope with rapidly changing loads than are diesels.

E. Carburetted engines have an inherent problem when used on rough terrain. Operation at steep angles, side slopes and violent sudden movements can result in carburetor flooding or, conversely, starving. There are a number of methods used to control this problem but the potential is always there. This particular aspect of rough terrain vehicle design must be given careful evaluation when selecting the engine and carburization system. The problem is particularly bad on small vehicles and, particularly, in the absence of a suspension system.

Diesel Engine

A. Diesel engines are typically more reliable with a longer service life than gasoline engines. Reliability improvement is in the range of 25% to 40% and service life is at least twice as long, commonly in the range of 10,000 hours.

B. Diesel engines have a lower fuel consumption rate. This reduces operating costs but, in addition, reduces the size of fuel tanks required for a given duty cycle.

C. Diesel fuel is probably more available in the area where the RPGV will be operating than will be gasoline. In addition, a diesel engine can be adjusted to run on turbine fuel such as JP-4, JP-5, or JP-8.

D. Diesel engines have a major problem with cold starting. This is a consequence of using the heat of compression for ignition rather than a spark plug. Industrial diesel engines usually are equipped with a number of aides for assistance in cold starting, such as crankcase heaters, manifold heaters, glow plugs, and either injectors. However, even with these starting aides, starting at extremely low temperatures (below -20°F) is often a serious problem.

E. Diesel fuel is less volatile than gasoline and is normally considered safer and less prone to explosion if the tank is penetrated by small arms fire or shrapnel.

Based on reliability, fuel availability, and survivability, a diesel engine seems the better choice. Diesel engines are manufactured in two basic styles; air cooled and water cooled. Which of these styles is better suited for the RPGV requires a more detailed analysis than is appropriate for this study. However, assuming the vehicle will be armored to some degree may mean a restricted air flow around the engine. If this turns out to be the case, then water cooled is the better design.

The engine size and horsepower necessary for the RPGV depends on four main factors.

A. Wheelbase or track length

B. Track width or lateral spacing between the tires

C. Gross vehicle weight

D. Maximum vehicle speed and gradeability

A relatively small vehicle such as the RPGV will require 10 to 15 horsepower per ton of vehicle weight.

Finally, the engine selection must also be based on the rough terrain operation of the vehicle. Many engines are not designed to accommodate operation at steep angles. There are a number of factors involved in this, but probably the most important is the possibility of the oil sump level shifting to the point that the oil pump cannot provide proper lubrication.

4.2.1.4 <u>Characteristics - Basic Vehicle</u>.

The discussion, thus far, has centered around the type of chassis, undercarriage, transmission and engine which should be used on the RPGV. There has been only limited consideration given to the actual interface of the vehicle with mine detectors, sensors and marking systems. However, as will be discussed later in this report, the sensors and detectors do not really influence the overall vehicle configuration very much. The vehicle configuration is, for the most part, determined by the selection of undercarriage, transmission and engine size. The various systems needed for marking and detection can be accommodated within the basic configuration determined by analysis of these three major factors.

The analysis indicates that a wheeled undercarriage is the optimum approach for the RPGV and the remainder of the discussion will be centered on this type chassis. It is important to note that the chief investigator for this study has many years of experience in the practical design and application of off-the-road all terrain vehicles. Much of the previous and following discussions, statements, criteria and analysis is based on this accumulated experience and knowledge of the chief investigator and supporting staff.

4.2.1.4.1 Physical Size.

The RPGV will use a wheeled undercarriage. A vehicle of this size and type will not require more than three wheels per side, six wheels total. Selection of the tire size must be based on two factors:

A. Capacity. Each tire should have a capacity rating of 1/4 to 1/3 of the gross vehicle weight.

B. Ground Pressure. The tire diameter and width must be selected to produce a ground pressure in the range of 10 to 15 psi.

Tire selection also affects other operational parameters such as drawbar pull, gradeability, shock attenuation and survivability. In addition, experience has shown that very small tires are not suited for rough terrain operation. It is difficult to climb over obstructions, negotiate ditches, etc., with small tires.

The weight of the RPGV will be in the range of 4000 to 12,000 pounds. This weight range is somewhat arbitrary and depends on how much armor is added. A GVW of 4000 pounds is believed to be a lower limit of practical design. A weight much over 12,000 pounds pushes the vehicle out of the "small" class. Of course, "small" is also arbitrary. A GVW of 12,000 pounds is "small" compared with a tank; it is quite "large" compared with an automobile. The rationale for selecting 12,000 pounds as the upper limit for "small" follows.

A. It has been determined that it is desirable for the vehicle to be the minimum practical size.

B. The smallest tires which are suitable for this application and for use on rough terrain will be about 2 feet in diameter.

C. Each tire must be rated for at least 1/4 of the GVW. The maximum capacity of commercially available tires in the 24 inch range is about 3000 pounds.

D. Four tires rated at 3000 pounds each is a total capacity of 12,000 pounds.

About the smallest tire size which is practical for a rough terrain vehicle of appreciable size is 24 inches in diameter. Selecting a tire 24 inches in diameter by 8 inches wide and calculating the ground pressure gives the following results:

GVW (Pounds)	Ground Pressure (PSI)
4,000	5.8
6,000	8.7
8,000	11.6
10,000	14.5
12,000	17.4

It can be seen that a 24 x 8 tire is acceptable for a GVW up to about 10,000 pounds but is marginal if the weight goes into the 10,000 to 12,000 pound range. A larger diameter or wider tire may be desirable if the GVW goes over 10,000 pounds.

Of course, not every combination of tire diameter and tire width is commercially available but, in the 24 O.D. by 8 width range, there are several standard tires capable of meeting the capacity requirements. Using 24 inch diameter tires with a four inch spacing between tires produces a minimum vehicle length of 80 inches. A reasonable overall vehicle length will be about 100 inches or a little over 8 feet.

The vehicle width is more difficult to pin down. It depends on track width, size of the side frames, length of hydraulic drive motors, width of gearboxes and size of the engine. However, experience with this type vehicle indicates that a width of less than about 60 inches is not practical. A reasonable and practical goal for the RPGV is in the range of 65 to 75 inches.

The vehicle height is dependent on the undercarriage design and physical size of the engine. Using the above criteria for the undercarriage and assuming an engine in the 40 to 50 horsepower range, the overall vehicle height will be 60 to 70 inches.

In summary, using the maximum dimensions estimated and using a "middle of the road" for weight, the RPGV will have the following physical characteristics.

Gross Vehicle Weight - 8000 pounds

Length - 100 inches

Width - 75 inches

Height - 70 inches

Tires - Six, 23 inches diameter x 8 inches wide

Ground Pressure - 11.6 psi

Engine - 50 hp (12.5 hp/ton)

4.2.1.4.2 Operational Characteristics.

4.2.1.4.2.1 Speed.

The upper limit of practical design for this type vehicle is about 20 mph. Above this speed, suspension systems become necessary and transmission design is difficult. However, a speed of about 10 mph is more practical and enhances overall operation, reliability and rough terrain performance. The maximum vehicle speed should be based not on what is technically possible, but on what is operationally necessary. There are three operational modes or conditions which determine the vehicle speed.

A. Searching for mines. The vehicle speed while searching for mines is limited by the responsiveness and sweep rate of the sensors and necessity to stop or turn the vehicle when a mine is detected. A vehicle speed of 10 mph is equal to a forward velocity of about 15 feet per second. Assuming a search path 10 feet wide means a surface area of 150 square feet must be searched each second at a vehicle speed of 10 mph. This seems to be far beyond the capabilities of any practical off-road detection system or its human operators. The conclusion of this argument is that 10 mph is much more than is needed. A practical vehicle speed while searching for mines will probably be in the range of 1 to 3 mph which covers an area of 15 to 45 square feet per second.

B. Roving cross country. In this mode of operation, the vehicle is moving across open ground, operated remotely, but is not searching for mines. Depending on the nature of the mission and type of terrain, a speed in excess of 10 mph may be advantageous. However, practical consideration of operation on rough terrain and remote steering from a television monitor will probably limit the vehicle speed to less than 10 mph. In addition, unless the vehicle is used for some type of long range reconnaissance, it is hard to see a real advantage in high cross country speed.

C. Transfer of RPGV between locations. This mode of operation is simply moving the RPGV from one "work area" to another. This could be accomplished over prepared surfaces or cross-country. In either case, good ground speed is very advantageous. In fact, when moving over roads, a speed of 40 to 50 mph would be desirable. This type speed is out of the question for the RPGV and, certainly, it would not be possible to remotely control the vehicle at such speeds effectively and safely. Fortunately, there is a ready solution to this problem. The RPGV is useless without its control and monitor vehicle. Therefore, wherever the RPGV is, the control vehicle will also be. The RPGV could easily be towed behind the control vehicle on a small transport trailer. This effectively provides the high speed transfer capability without introducing prohibitive complexity and cost into the RPGV.

In summary, the operational requirements seem to be more than satisfied by a vehicle speed of 10 mph.

4.2.1.4.2.2 Maneuverability.

The required maneuverability of the vehicle has already been discussed in some detail. The capability of turning about its own center is a major feature of the undercarriage and transmission concept. A shorter turning radius is not possible.

4.2.1.4.2.3 Adverse Terrain Operation.

The RPGV must be capable of operation on adverse terrain. Adverse terrain is defined as "rough terrain" such as cross country and unfavorable ground conditions such as soft soil or mud. However, there are no generally accepted technically accurate definitions for the phrases "adverse terrain", "rough terrain", and "unfavorable ground". The off-road vehicle industry and the military services have been trying for a number of years to develop specific quantitative criteria to define how rough is "rough", how soft is "soft", etc. This is similar to the previous question of how big is "small", but it is not as easily resolved.

Attempts to specify rough terrain capability in quantitative terms have been in three major areas.

A. The ability to climb obstructions of a specified vertical height.

B. The ability to cross ditches of a specified width.

C. The ability to operate on grades and side slopes of a specified steepness.

Meeting the first two of these specified criteria does not mean the vehicle will be good when operating cross country. The reason is that the criteria are only remotely related to the capability of operation on rough terrain. The most popular method of specifying rough terrain, at the present time, is the capability of operation on specific grades and side slopes. This criteria really has more to do with stability and tractive effort than rough terrain. However, in general, experience has shown that, if a vehicle has the stability and power to operate on grades and slopes in the range of 35° to 45°, it will be capable of operation on almost any natural terrain. Rough terrain capability for off-road construction equipment is normally specified in terms of "gradeability". The RPGV should be capable of operation on grades and slopes of 40°, minimum.

Establishing specific quantitative criteria and requirements for soil conditions has proven equally difficult. There are so many variables related to soil conditions and trafficability that the problem defies solution. The difficulty is that soil has no uniform properties and its bearing capacity, as well as load-sinkage relationship, cannot be expressed in simple form. The trafficability of a particular type of soil is determined by the degree of cohesion between soil particles, friction between particles, soil density, moisture content, and conditions of overlaying and underlying vegetation. An additional complication is the tendency for stratification in soils. Surface and subsurface parameters may be (in fact, usually are) quite different. In a given section of natural terrain, the soil conditions can and will show considerable differences at points only a few meters apart. In addition, the passage of even a single vehicle will normally radically alter the soil. Thus, a vehicle may cross a given soil one time but, if the same path is traversed again, the vehicle becomes immobilized. This is a well known, although poorly understood, consequence of radical alteration of the soil. Thus far, it has not been possible to define a given soil in specific quantitative terms sufficient for use as a vehicle design criteria.

Assuming the soil could be defined, the problem becomes how to design a vehicle with the capability of negotiating a soil so defined. The ability of a vehicle to pass over a given soil depends on three factors:

A. Flotation

B. Tractive effort or force

C. Resistance to motion

The relationship between these factors and the capability of operation in soft soils has been studied in great detail producing a number of mathematical models for prediction of vehicle performance. As might be expected, these models are complex and different models are needed for different types of soil. A vehicle designed for maximum operational capability in a frictional-cohesionless soil (dry sand) will probably do poorly in a cohesive-frictionless soil (supersaturated clay). The converse is also true. All three factors are important and must be considered in vehicle design, however, in a particular given soil condition, one factor may be more important than the others. It is not true that ground pressure alone or even primarily defines the vehicle operability in all situations. Experiments have shown that, in certain types of soil, a higher ground pressure vehicle may perform better than a low ground pressure vehicle.

The three factors for ground mobility are analogous (to a degree) to the three major factors in aircraft design; Lift, Drag and Thrust. Stating that one vehicle is better than another based on flotation (ground pressure) alone is like evaluating aircraft performance based solely on a comparison of lift.

Perhaps the most determined effort to quantitatively define soils and develop mathematical models for vehicle design has been by the U.S. Army Materiel Command. The U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, has been engaged in the study of trafficability of soils for a number of years. These investigations have produced a method of measuring soil strength which is expressed in terms of a Rating Cone Index (RCI). A set of empirical equations allows calculations of a Mobility Index (MI) for a given vehicle. The MI is related to another parameter called the Vehicle Cone Index (VCI) by yet another empirically derived equation. By definition, a particular vehicle with a certain VCI can pass over a soil with an equal RCI. This seems to be exactly what is needed and a calculated VCI will be developed for the RPGV based on the WES method.

The Mobility Index (MI) is based on 8 factors as described below:

$$MI = \left[\frac{\text{contact pressure factor} \times \text{weight factor}}{\text{tire factor} \times \text{grouser factor}} + \text{wheel load factor} - \text{clearance factor}\right] \times \text{engine factor} \times \text{transmission factor}$$

$$\text{contact pressure factor} = \frac{\text{gross weight, lb}}{\text{tire width, in.} \times \frac{\text{outside dia. of tire, in.}}{2} \times \text{No. of tires}}$$

Weight Factor:

Weight Range, lb $\left(\frac{\text{Gross Vehicle Wt, lb}}{\text{No. of axles}}\right)$	Weight Factor Equations
2000	Y = 0.553X
2,000 to 13,500 lb	Y = 0.033X + 1.050
13,501 to 20,000 lb	Y = 0.142X - 0.420
20,000 lb	Y = 0.278X - 3.115

where

$$X = \frac{\text{gross vehicle wt(kips)}}{\text{No. of axles}} \quad \text{and } Y = \text{weight factor}$$

$$\text{Tire Factor} = \frac{10 + \text{tire width, in.}}{100}$$

Grouser Factor:

With chains = 1.05
Without chains = 1.00

$$\text{Wheel load Factor} = \frac{\text{gross weight, kips}}{\text{No. of wheels (duals count as one)}}$$

$$\text{Clearance Factor} = \frac{\text{clearance, in.}}{10}$$

Engine Factor:

10 hp/ton = 1.00
10 hp/ton = 1.05

Transmission Factor:

Hydraulic = 1.00
Mechanical = 1.05

For the RPGV at a GVW of 8000 pounds, these factors calculate to as follows:

$$\text{Contract Pressure Factor} = \frac{8000}{8 \times 24/2 \times 6} = 13.89$$

$$\text{Weight Factor} = 0.033 \times \frac{8}{3} + 1/05 = 1.14$$

$$\text{Tire Factor} = \frac{10 + 8}{100} = 0.18$$

Grouser Factor = 1.00

$$\text{Wheel Load Factor} = \frac{8}{6} = 1.33$$

$$\text{Clearance Factor} = \frac{14}{10} = 1.40$$

Engine Factor = 1.00

Transmission Factor = 1.00

$$\text{MI} = \frac{13.89 \times 1.14}{0.18 \times 1.00} + 1.33 - 1.40 \times 1 \times 1 = 87.9$$

The VCI is calculated from the following formula.

$$\text{VCI} = 11.48 + .20\ \text{MI} - \frac{39.2}{\text{MI} + 3.74} = 28.6$$

(Note: The lower the VCI, the better the vehicle performance with a lower limit for practical vehicle design of about 10.)

A VCI of 28.6 is very good and there are few vehicles (mainly tracks) which are better. The WES has also developed empirical formulas for allowable tractive force and resistance to motion in soils of a given RCI. For the RPGV, a soil with an RCI of 28, will allow a maximum tractive force of 3840 pounds. The resistance to motion will be 960 pounds.

The WES system has never come into general use, even in the military. And it is almost unknown in the off-road vehicle industry. The reason is that the system is not very general in nature and is very limited as to the soil type and conditions for which the system holds true. Experience has shown that the calculated VCI versus a VCI determined by test or experiment can be very close or can be off by 100% to 150%, depending on conditions and design of the vehicle.

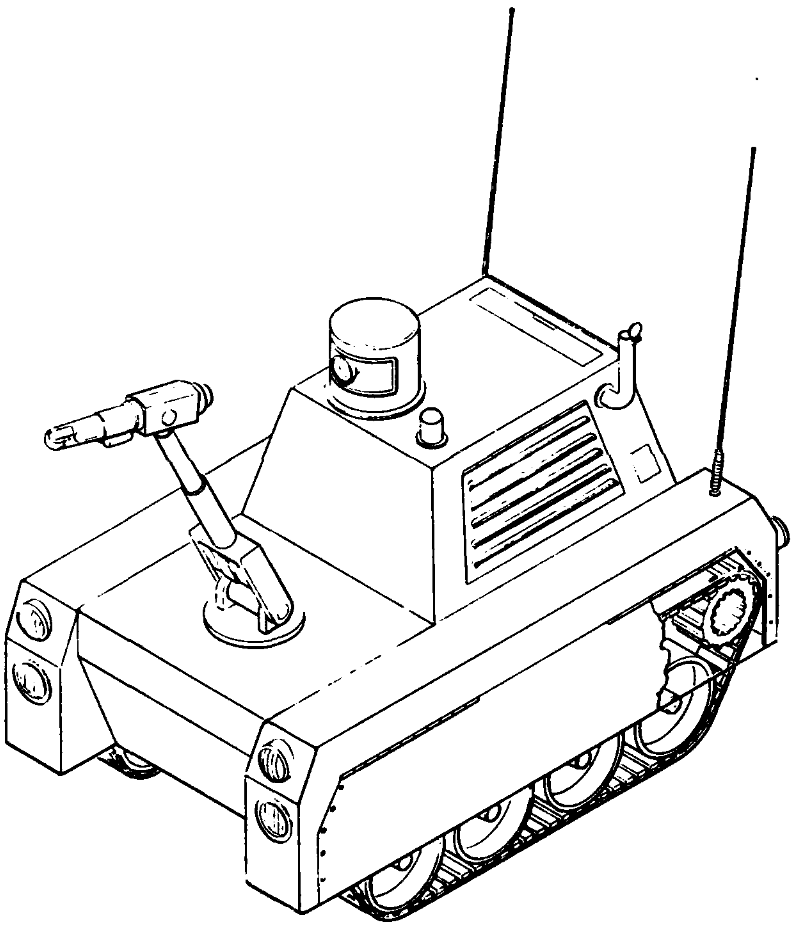
The most common method of specifying soft soil operability is still ground pressure which is used almost exclusively in industrial vehicles. A tracked vehicle will normally have a ground pressure in the range of 5 to 10 psi. This is about as low as any industrial vehicle gets. The ground pressure for the RPGV should be in the range of 10 to 15 psi.

The meaning of ground pressure can be more easily appreciated by a simple comparison with an average man. The average man standing still exerts a ground pressure of 3 to 4 psi. Thus, the average man standing on a "3 to 4 psi soil" would sink of his own weight. This same man at a normal walk produces ground pressure in the range of 8 to 12 psi. Generally speaking, a normal walk is difficult on "10 psi soils" and impossible on "5 psi soils".

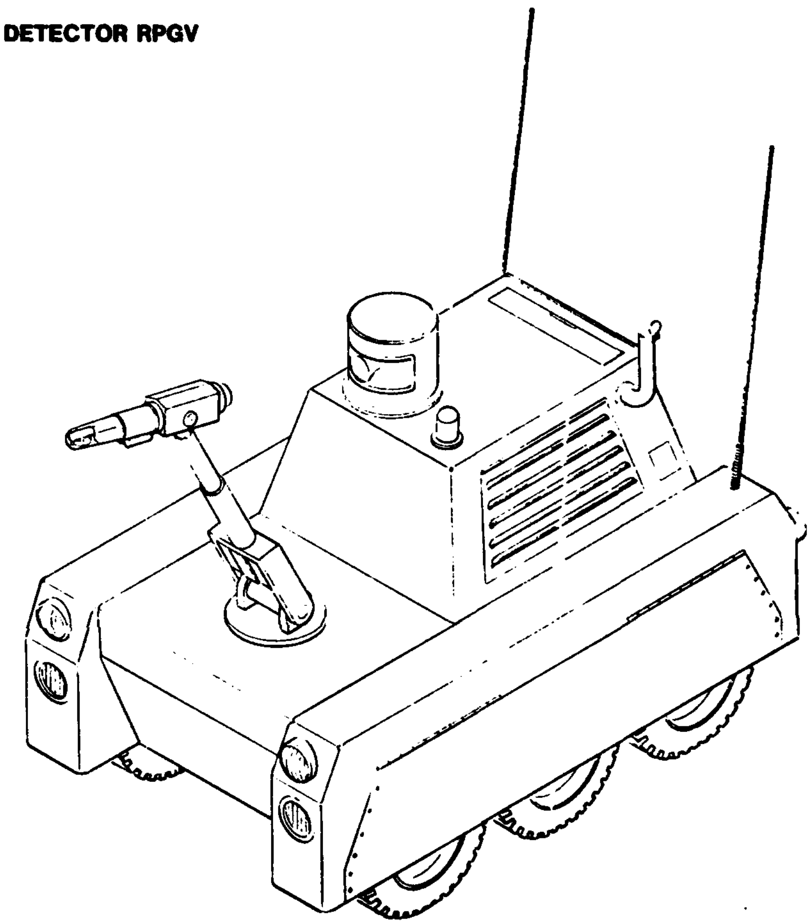
4.2.1.4.3 Vehicle Configuration for Survivability and Mission Accomplishment.

Mounting of equipment and maximization of survivability factors are the primary considerations used in developing the RPGV configurations (see conceptual drawings on next two pages). Equipment uses determined the vehicle areas where the detectors,

BASIC CONCEPT-MINE DETECTOR RPGV



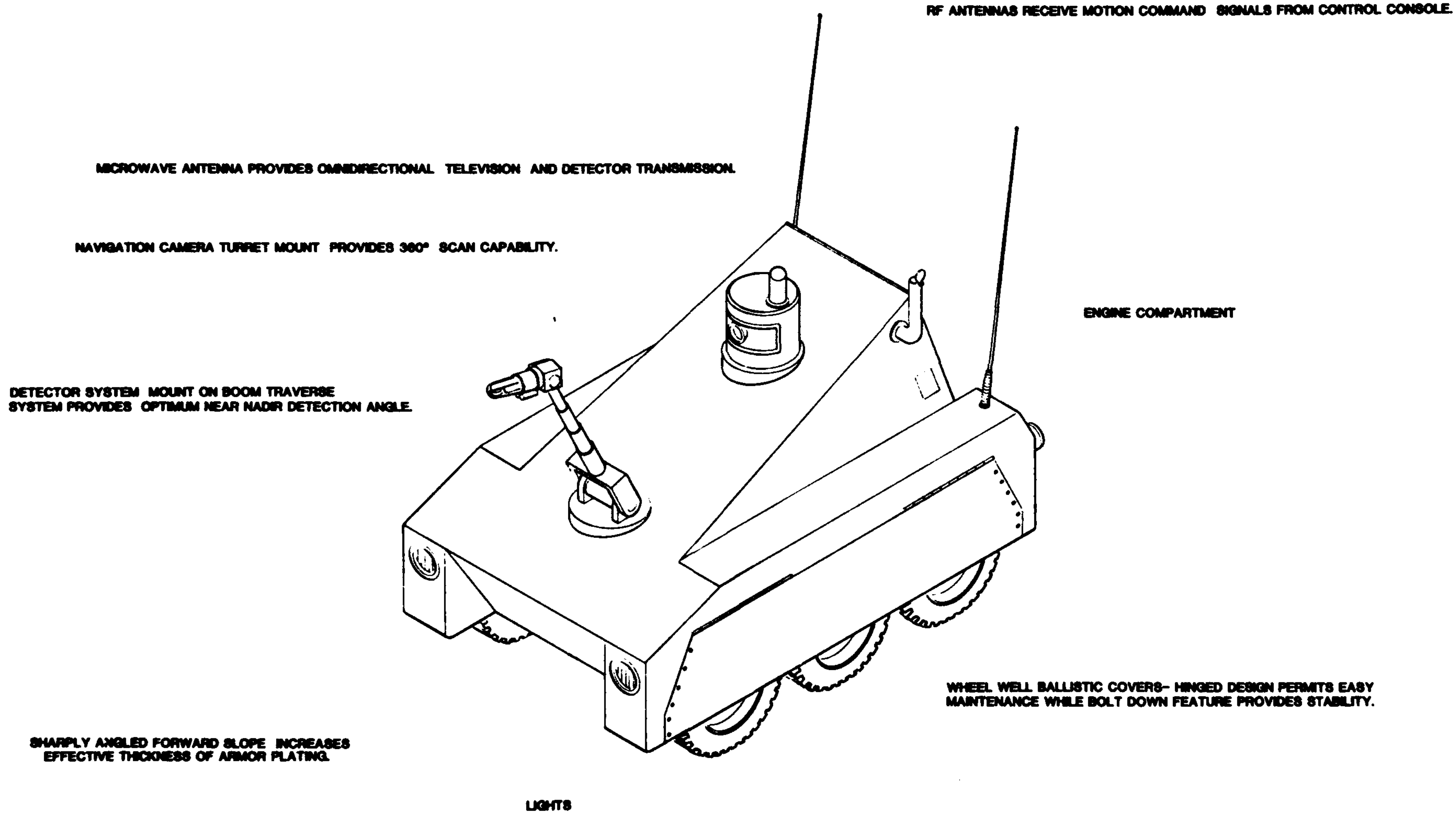
TRACKED VERSION



WHEELED VERSION

STANDARD MFG. CO. INC.		
BASIC CONCEPT-MINE DETECTOR RPGV		
98296	E	6

ENHANCED SURVIVABILITY RPGV MINE DETECTOR CONCEPT



STANDARD MFG. CO., INC.	
ENHANCED SURVIVABILITY RPGV MINE DETECTOR CONCEPT	
98296 E	6

cameras, lane marking devices, and mine neutralization systems would be placed. Obviously, the detector systems and mine neutralization devices would be located at the front of the RPGV, the lane markers on the side, and the navigation camera near the highest point on the vehicle. For protection, antenna location is desirable at the rear of the RPGV, however, mounting the television antenna on top is necessary in order to maintain line of sight capability when driving tangentially or toward the controller.

Location of the engine in the rear serves several purposes. First, it insures that the RPGV remains stable on the four rear wheels during normal operation. This aids steering and helps stabilize the cameras and detector. Second, it provides a counterweight for an anti-tank mine removal device or an anti-personnel mine neutralization device, if used. Third, location in the rear permits the front slope of the engine compartment to be angled for improved ballistic protection. The sloped top surface, covered wheel wells, hinged plates over the wheels, and angled lower front plate all contribute to vehicle survivability. The wheel wells and front plate may also contribute to RPGV amphibious capability.

Maintenance access doors will be needed for the engine compartment, the navigation camera and electronics area, and boom and mine removal system area. Development will need to consider the ease of access along with location and hardening for survivability. The engine access plate, for example, will probably be on the rear slope of the RPGV, but, due to possible vehicle use clearing a second lane while returning to the controller, that plate will probably be thicker than the more obliquely angled forward slope.

Survivability trade-offs also need to be weighed with respect to the RPGV's tires. The tire survivability could be improved in an antipersonnel minefield by increasing the diameter. However, the resulting longer vehicle would lose some survivability due to less maneuverability and larger target profile.

Some form of lighting will probably be needed, even if it is only a blackout drive system helping drivers see the RPGV. These would be located as near as possible to the RPGV's corners.

A removable towbar could be added to units with disengaging drive systems enabling them to be towed without the use of a trailer. If a mine neutralization device is included on the RPGV, the towbar would be moved to the rear of the unit. Both the towbar and the mine neutralization exterior equipment can be developed for removal and attachment elsewhere on the unit, cleaning the unit's shape for airlift or airmobile transport, missions not using the equipment, and rapid replacement of battle damaged parts.

Plate thickness in various areas of the RPGV can be expected to vary according to the amount of protection needed to counter each threat. Minimum thickness and Kevlar reinforcement should be considered due to weight considerations. The Army has done studies on this type ballistic defense system already, particularly for protecting ammunition. Necessary plate thicknesses can be expected to be derived from those studies.

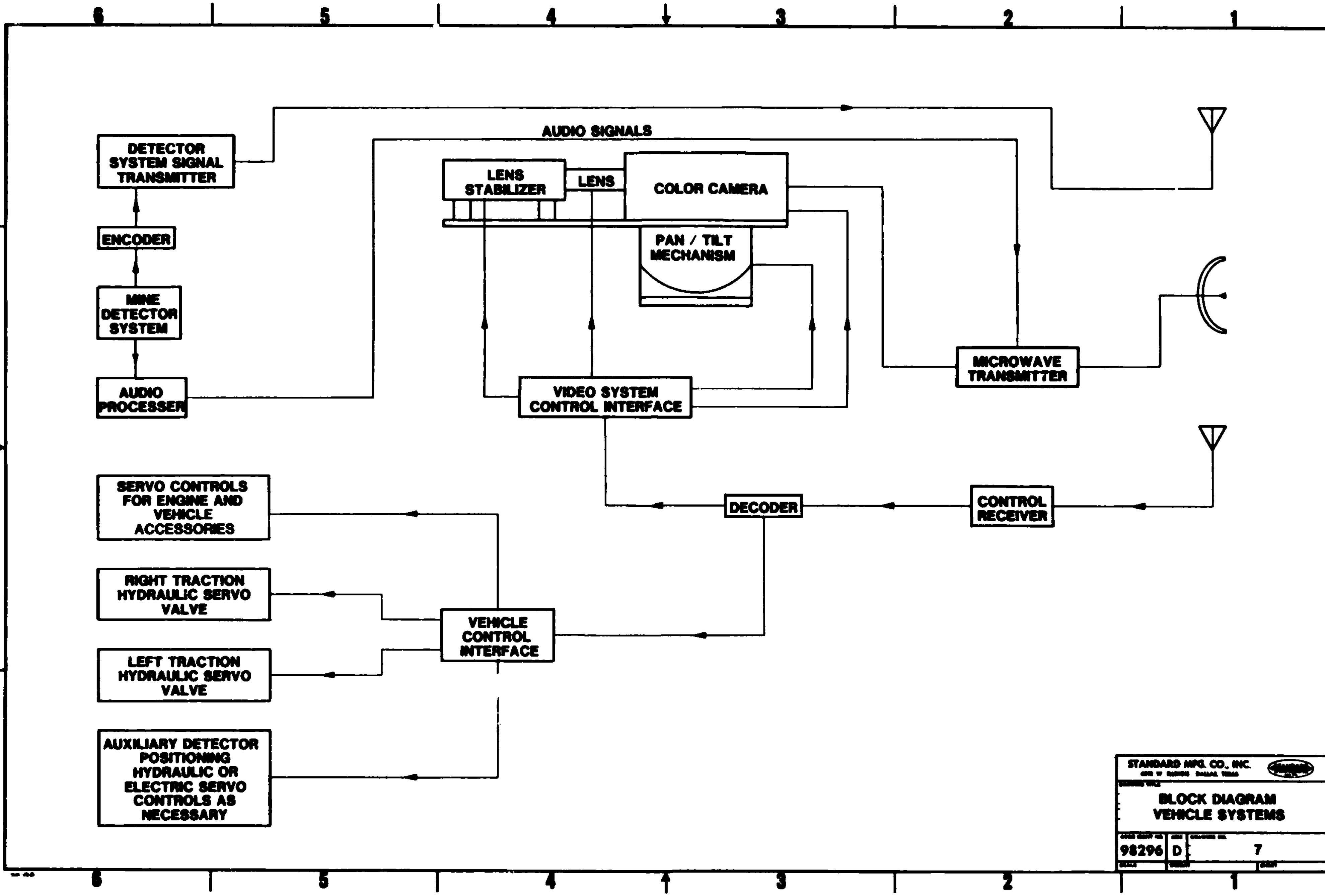
4.2.1.5 Vehicle Control System.

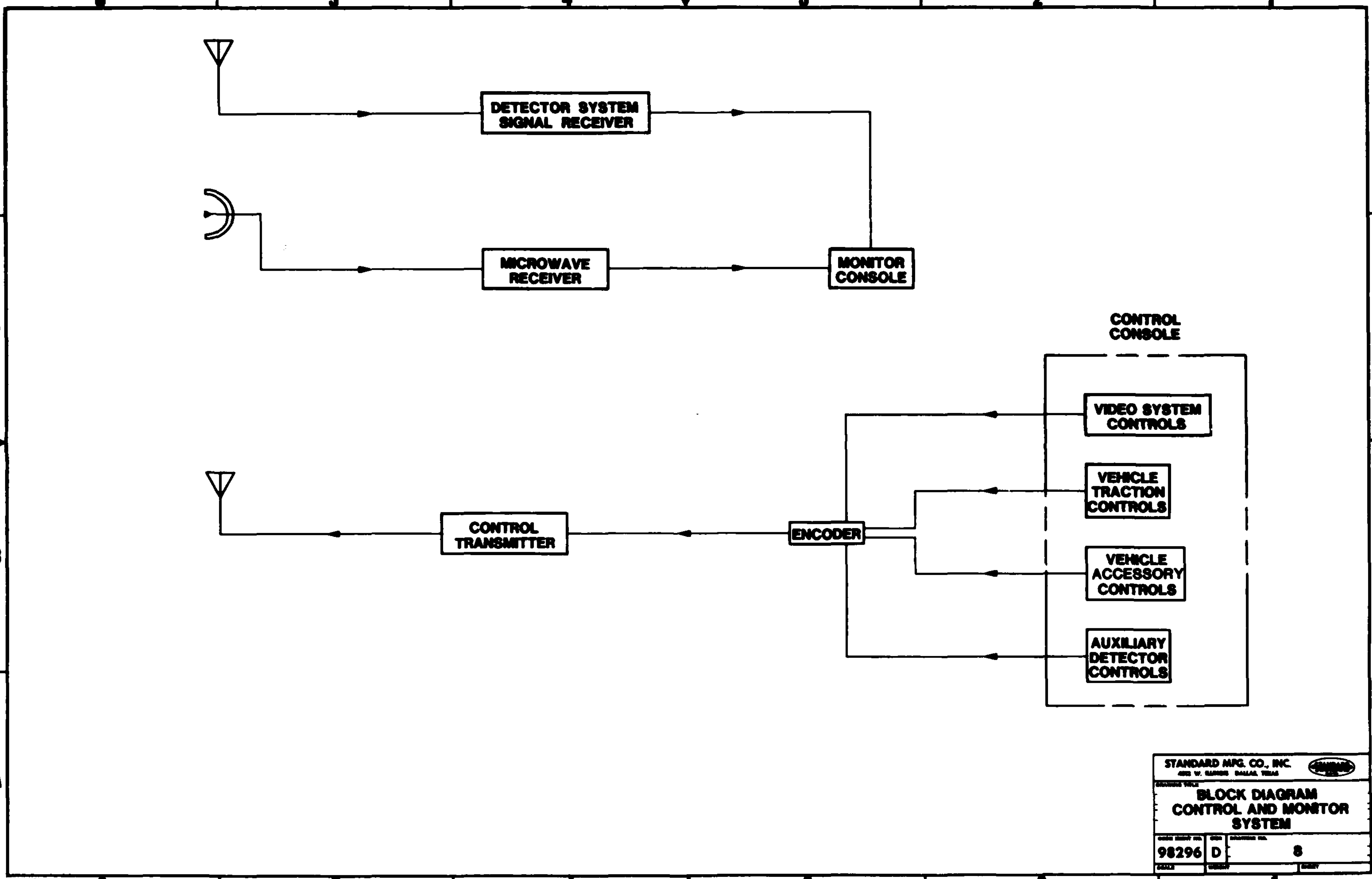
The vehicle control system refers to the physical control and operation of the RPGV (equipment shown in drawings on next two pages). This includes control of vehicle speed, direction of travel, steering, and braking. The vehicle control system also includes secondary functions such as starting/stopping the engine and auxiliary functions such as turning on the vehicle lights (if any). There may also be a number of vehicle and engine monitor functions which are desirable or necessary. This might include engine oil pressure, temperature, etc.

The RPGV will probably include a visual guidance system. This system will be nothing more than a television camera to enable the operator to "see" where the vehicle is going. The video system will be discussed in detail later. However, there are certain control functions associated with the video system. In other words, the camera position and angle must be adjustable by the operator from the remote console. Control of the camera is accomplished by the same techniques as control of the vehicle.

The vehicle will also include some type of mechanism to position, sweep, and rotate the mine sensors. Regardless of what type mechanism this turns out to be, the principles for control of the mechanism are the same as for the vehicle and camera.

Thus, the discussion of methods for control is applicable to everything on the RPGV which must be positioned, tilted, shifted, switched, or turned by the operator working from the remote control console.


DETECTOR SYSTEM SIGNAL TRANSMITTER
ENCODER
MINE DETECTOR SYSTEM
AUDIO PROCESSER
AUDIO SIGNALS
LENS STABILIZER
LENS
COLOR CAMERA
PAN / TILT MECHANISM
VIDEO SYSTEM CONTROL INTERFACE
MICROWAVE TRANSMITTER
CONTROL RECEIVER
DECODER
VEHICLE CONTROL INTERFACE
SERVO CONTROLS FOR ENGINE AND VEHICLE ACCESSORIES
RIGHT TRACTION HYDRAULIC SERVO VALVE
LEFT TRACTION HYDRAULIC SERVO VALVE
AUXILIARY DETECTOR POSITIONING HYDRAULIC OR ELECTRIC SERVO CONTROLS AS NECESSARY
STANDARD MFG. CO., INC.
BLOCK DIAGRAM
VEHICLE SYSTEMS
98296
D
7

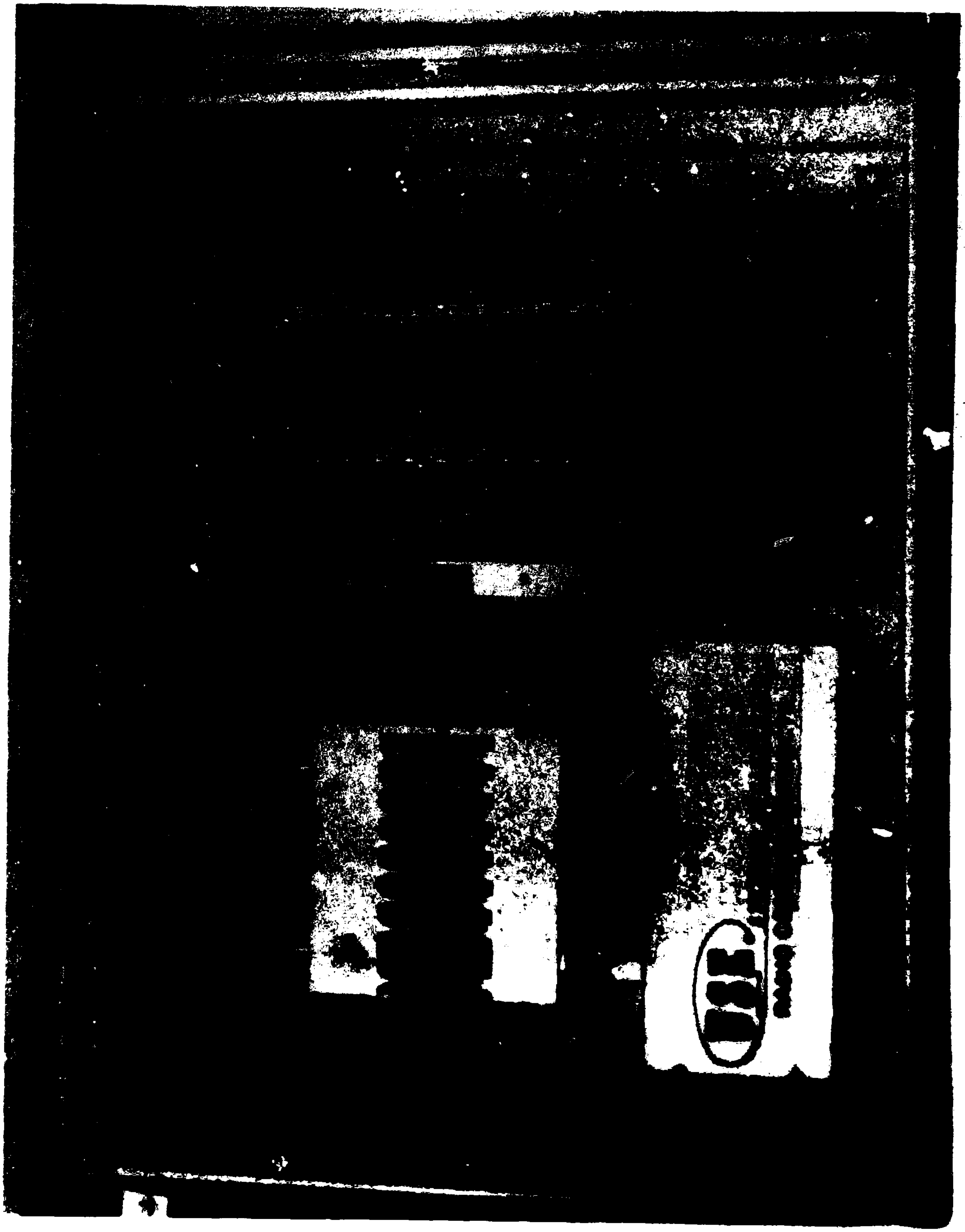

DETECTOR SYSTEM SIGNAL RECEIVER
MICROWAVE RECEIVER
MONITOR CONSOLE
CONTROL CONSOLE
VIDEO SYSTEM CONTROLS
VEHICLE TRACTION CONTROLS
VEHICLE ACCESSORY CONTROLS
AUXILIARY DETECTOR CONTROLS
ENCODER
CONTROL TRANSMITTER
STANDARD MFG. CO., INC.
BLOCK DIAGRAM CONTROL AND MONITOR SYSTEM
98296
D
8

The vehicle will be controlled by signals transmitted over radio frequency (RF) from the control console to the RPGV. This is a well known and fully developed technology which has been used in numerous practical applications for over 40 years.

The system shown in photograph 5 displays the receiver, digital decoder and relay unit on the left and the vehicle control unit with carrying straps, the battery recharger, a typical hydraulic servo system for two controls, and a spare battery for the control unit on the right. The size of the system (indicated on the tape measure) can be significantly reduced, if necessary, for fitting in a production vehicle. The individual photographs of the components (photos 6 and 7) reveal more details. Shown on the receiver unit are the racks for printed board circuitry and connection points for thirty servo control units, indicating both the unit's current capacity and its potential for rapid upgrading. The control unit's simplicity is shown clearly on photo 7. Not only are controls for speed and turning included on the handset, but also present are engine start, fuel line, low or high range operation, and four other unspecified controls. The battery charger is capable of recharging four of the NiCad batteries at a time and can be adapted for use with 234 volt AC input as well as 117 volt AC.

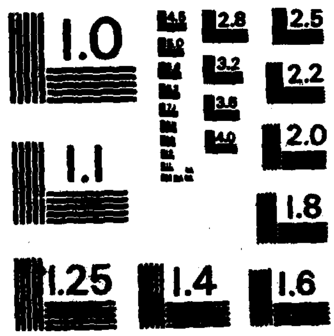
In addition to the remote control radio link, it may be necessary to include a system to guide the vehicle on a straight course. Due to variances in pump displacement, friction, and irregular terrain, the RPGV may begin to veer off course as it drives along. An automatic counter system could be included so

PHOTOGRAPH NO. 5
RADIO CONTROL EQUIPMENT

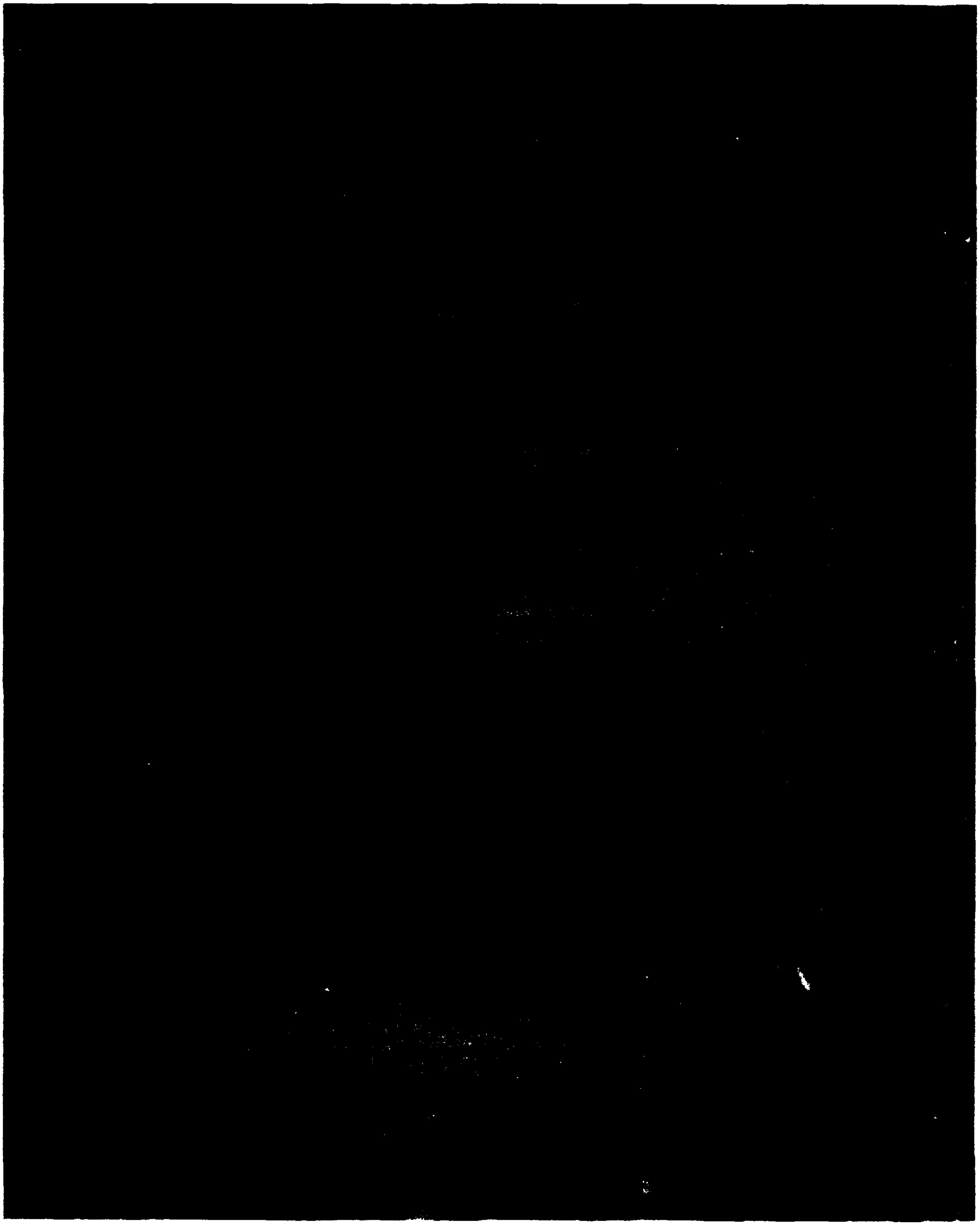


AD-A122 001 REMOTE CONTROLLED VEHICLE MOUNTED MINEFIELD DETECTOR SYSTEM(U) STANDARD MFG CO INC DALLAS TEX D W HUDLER ET AL. NOV 82 R6929-4 DAAK70-82-C-0052 2/2

UNCLASSIFIED F/G 19/1 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



PHOTOGRAPH NO. 7
RADIO CONTROL TRANSMITTER
AND SUPPORTING COMPONENTS

that all wheels would be turned at the same rate. This standby system could be set and activated from the control console. By including vehicle speed and detector sweep rate in the programming, it would be possible to insure straight line travel through a minefield and observation of the entire lane by the detector.

An optional control feature may be included in the RPGV-control unit interface. The vehicle motion area of the control panel can be made to disconnect from the control unit, mount on the RPGV at an operator's platform, and connect by cable into the vehicle. In this way, the RPGV could be driven in a direct control mode without use of the radio, television, or remainder of the control console. This could be very advantageous in motor parks or when it is desirable to move the vehicle without transmitting a radio signal.

4.2.2 Investigation of Mission Systems.

4.2.2.1 Approach to Mine Detectors.

Due to proven performance and current stockpiles of hand-held portable detectors, the feasibility of mounting them on a vehicle was evaluated. This proved to be undesirable from several viewpoints. The slow sweep rate of approximately 2 feet per second for the AN/PRS-8 provides a speed of only 400 feet per hour when clearing a path wide enough for a tank to drive through the minefield. The tendency to produce false alarms when used in rough terrain would be increased by the operator's lack of depth perception when viewing the remote control monitor. The operator cannot maintain detector height of less than 1-1/2 inches (required on the AN/PRS-8 and AN/PSS-11), avoid obstacles, and keep the detector head parallel to the ground when positioned away from the vehicle. The training requirement to maintain detector proficiency was regarded as high, at least 2 hours practice per week, and was, therefore, also undesirable.

The type of system employed by the Vehicle-Mounted Road Mine Detector System (AN/VRS-5) was also deemed inappropriate due to the extreme difficulties encountered in determining a means of negotiating obstacles over 3 inches in height or depth. System unsuitability for vegetated or rough terrain was obvious.

From the evaluation of the AN/VRS-5, AN/PSS-11, and AN/PRS-8, it became evident that a completely different type of detector was needed. The RPGV detector system has to be situated at a height to avoid obstacles and not be affected by variations in ground clearance. Due to the all weather nature of warfare and the probability of minefield observation, detection through snow, smoke and dust is required. These capabilities imply use of a system which will also detect buried mines, a desirable feature due to the mine laying capabilities of the Soviet PMR-3 mechanical mine-planting trailer and the GMZ mine-layer. Radar and infra-red systems were determined to be the probable primary systems due to the specular characteristics of mines irradiated by these systems during testing by the Environmental Research Institute of Michigan. Also desirable is a second means of detection in order to verify detections and reduce false alarms. A television camera was evaluated as suitable for this task.

4.2.2.2 Potential Detectors.

4.2.2.2.1 Radar.

The possibility of using a radar system for primary detector needs to be tested more thoroughly. Accurate location is probable, as indicated by the sharp peak in radar cross section measurements (see ERIM Report 138300-65-F1), however, detection probability of buried mines at that frequency is not acceptable. Ground penetration is possible at some other frequencies.

Conversations with people working in the radar industry indicated that S-band radar has good enough ground penetration, but no information is available concerning mine specular reflectance nor radar penetration through snow. Also, it was learned that Goodyear Aerospace manufactures a scanner device capable of approximately 100 feet of soil penetration for contour mapping. The size of the system is small enough to fit this application, but two drawbacks exist. The high cost of approximately $100,000.00 removes it from a cost standpoint, and the possibility of it not detecting plastic mines, although it would detect metal, poses questions concerning its operational desirability.

If clear signatures are produced by mines irradiated by a radar frequency capable of 2 to 3 feet of ground and snow penetration, that system provides some excellent advantages. Among these are all weather capability and fast system response. Systems which should be tested are short range radars and earth resources systems.

Use of radar mine detection systems involves acceptance of some tactical hazards or drawbacks. As with active IR systems, radar can be detected and targeted by enemy forces observing the minefield. Required antenna dimensions vary according to the wavelength used, and it is unlikely that the system can be made as compact as the active IR systems.

4.2.2.2.2 <u>10.6 Micrometer Laser IR Scanner</u>.

Applicability of an active infra-red system of this type is advocated in the final report by the Environmental Research Institute of Michigan, contract DAAK-70-78-C-0198, on Remote Detection of Minefields, Report No. 138300-65-F1. The strong specular reflectance from the PM-60 and TM-46 mines provide unmistakable signals when that signal strikes the detecting unit (i.e., camera lens). System interface with the vehicle navigation camera would be simple and direct using equipment commonly seen at televised sports events for split screen projection of two images on one screen.

The system is not completely proven nor without drawbacks, however. Through conversation with Mr. Henry McKenney, it was learned that testing by ERIM indicated good ground penetration for mine detection, but no tests were made for detection of a snow covered minefield. Testing was done with anticipated airborne application, so further testing will be needed to determine capabilities in adverse weather and detection probability when system is ground based. The anticipated 8.4% detection rate (ERIM Report No. 138300-22-T) for the airborne system would have to be significantly improved for surface vehicle application. This improvement is expected on the recommended vehicle design due to the near nadir viewing angle and shorter range. Use of an active IR scanner system also increases the chance of enemy detection and destruction of the vehicle. In addition, the laser IR scanner may require extra design work to eliminate eye hazard for operator safety.

4.2.2.2.3 Detection Verification and Navigation Systems.

Potential candidates for a detection verification system are a color television and/or a black and white system with infra-red circuitry and lens filters. The television can be used for navigation and detection and, when switched to IR mode, will detect high reflectance areas of the particular wavelength of infra-red not filtered.

4.2.2.2.3.1 Camera Systems Utilization.

Depending on vehicle characteristics, one or two cameras will be required. If the vehicle stops to scan an area, one boom mounted camera is sufficient. Navigation using the boom mounted camera will probably be slow and difficult due to the length of the boom necessary. In order to scan while moving, independent cameras projecting onto a split screen TV monitor provide optimum coverage. A one-camera method of observing both functions is splitting the images by use of mirrors or fiberoptic lenses. Some resolution capability is lost using these devices, however. Also lost are wide-angle to zoom lens capability (desirable when the RPGV is used for reconnaissance) and lens exchange to image intensifier and nighttime usage.

From the operator's standpoint, a navigation camera becomes necessary to see where the vehicle is going whenever the vehicle is around a corner, over a hill, or over approximately 100m away.

A color camera is desirable over a black and white for navigation or detection because of better object resolution, discernment capability of colors instead of approximate shades of gray, and increased knowledge of the vehicle area. This enhances mine detection while viewing the ground and enemy position location while viewing ahead. A zoom lens on either navigation or detection camera increases flexibility for wide field of view observation and inspection of suspected mines or positions. Black and white cameras are less expensive and can be adapted for infra-red capability without new or extensive design work.

Due to the need for constant monitoring of detection and navigation, two cameras appear to be required. Each needs to be capable of independent pan and tilt control, using equipment having automatic panning controls and a manual override. This will provide a set detection speed for the vehicle, insure inspection of the entire area within the lane, and provide navigational feedback while moving.

If one color camera and one black and white camera were used, it may become desirable to have both cameras on independent booms so that they could be used for either navigation or detection verification. In this circumstance, the black and white camera with infra-red detector circuitry would act as the detection system and the color camera would act as the navigation system. When a possible mine could not be verified using the IR or black and white circuitry, the second boom would extend the color camera over the suspected mine to improve verification probability. Both cameras would need to be enclosed. The ballistic protection for the detectors would be of a reinforced Kevlar resin on all sides with bulletproof glass over the lenses. The protection for the navigational camera would be similar, except for probable mounting in a small turret and addition of some steel plating.

4.2.2.2.3.2 <u>Additional Camera Components</u>.

4.2.2.2.3.2.1 <u>Fiberoptics</u>.

Extension of the camera lens by use of flexible industrial fiberscopes provides the distinct advantage of displaying a very small target on the surface of the vehicle. The camera(s) can be placed behind the armor plating with only the 1/2 inch fiberoptic cable and lens potentially exposed. Current production probes are made in lengths up to nine feet and are equipped with lenses varying from 20 to 80 degrees field of view. Prototypes are being tested to increase the available length to 18 feet. This additional length would enable fiberoptics use for a boom camera system without requiring the boom to support the camera's weight.

Testing of a fiberscope would be necessary prior to selection for the IR mine detector role or the vehicle navigation role. Currently, very little is known about fiberscopes with respect to infra-red transmissivity or interface with night vision devices. Although one model is designed for use with ultraviolet light and another for visible light, infra-red light may be absorbed by both models.

Other potential problems may be easier to solve. Increasing the operating temperature range can be done by use of heating wires. A small amount of custom design work could also enable development of split screen fiberscopes, with one fiberscope going to the detector boom and the other to a navigation lens mount.

4.2.2.2.3.2.2 Image Intensifier.

The camera system is limited to daytime use unless fitted with an image intensifier or vehicular lights. Lighting a battlefield is not tactically sound and was discounted as an option. The image intensifier results in a green picture with lower resolution than needed for use as primary detector. It is adequate for vehicle navigation and marking of mines and has the advantage of being a passive system.

4.2.2.2.3.2.3 Image Stabilizer.

Vibration and shock may cause sufficient picture aberration to necessitate use of an image motion compensator. These devices mount on the camera lens and clarify blurred images caused by vibration. Systems can work with cameras using infra-red, visible, or ultraviolet light media, making them compatible with both the observation and IR detector cameras considered for the RPGV.

4.2.2.2.3.3 Systems Integration Into Unit.

4.2.2.2.3.3.1 Camera System.

Unlike a home video tape system, the mine detector video system does not consist of merely a portable camera and monitor. Several pieces of equipment and controls are required to relay the desired picture to a remote monitor. The needed items are equipment for the radio link for the television signal and a group of devices for camera control. No separate power supply is required (unless the console is operated away from support vehicles) due to all systems being designed for DC power.

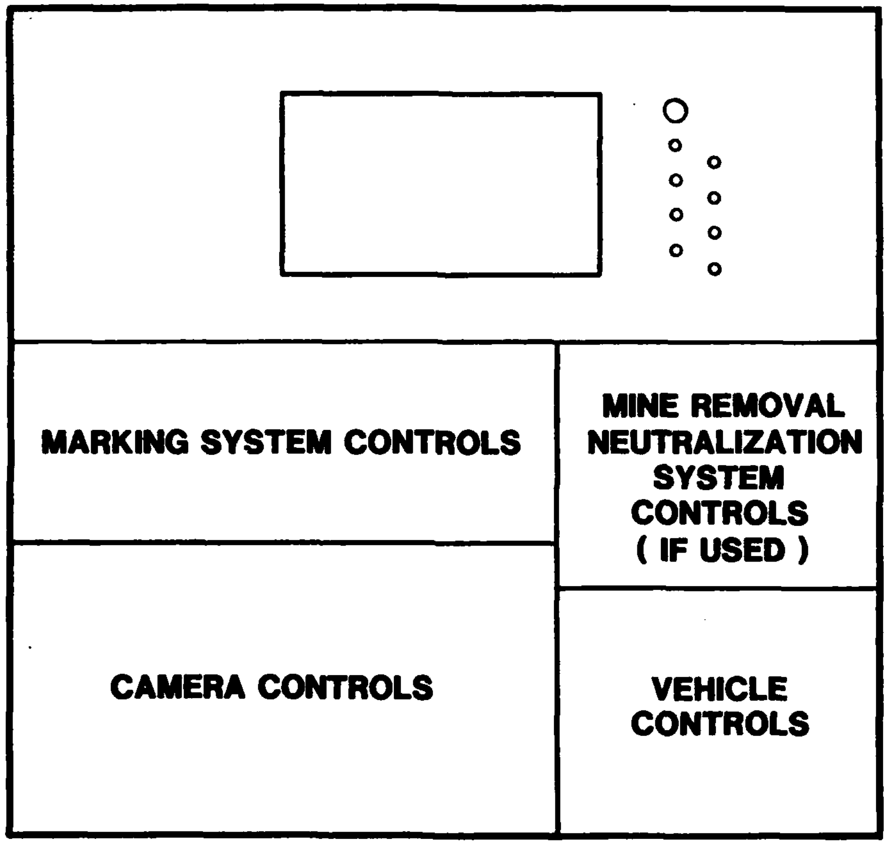
The radio link contains the following essential pieces of equipment: the microwave transmitter, an antenna, and optional split screen encoder mounted on the RPGV, and the microwave receiver and antenna mounted with the monitor on the control vehicle. The split screen encoder is desirable if 2 cameras are used on the RPGV, as it permits one operator to rapidly observe mine detection operations while driving the vehicle. Without split screen technique, a second complete system will be required for the detector system.

The camera control group uses less sophisticated equipment than the radio link for the picture. However, because there are more processes to control, there are more components. The functions of camera pan, tilt, focus, lens change, zoom, on and off, and lens stabilizer (if used) require separate servo-type controls. Use of a digital decoder and encoder enables these functions to all be transmitted on one signal carrier. Different pulse widths automatically cue the decoder switches to the correct servo units for motor activation. Two accessories, a modulation unit and a demodulation unit, permit the signals to be transmitted by radio waves instead of a wire command link. Guidance instructions will be initiated at the control panel by the operator, pass by wire through the digital encoder and the modulator to the radio transmitter. At the remotely controlled unit, the radio receiver picks up the signal, sends it into the wiring to the demodulator, the digital decoder, and on to the servo units to produce the desired movement. The heart of the system is the digital encoder and decoder. These units provide the capability to control the vehicle and, depending on model, one or more camera control systems using one radio frequency. Multiple camera control will be needed if a navigation camera is mounted separately from the detector system.

4.2.2.2.3.3.2 Monitor and Control System.

Vehicle mounting of the monitor and control system was deemed necessary due to size and weight of the monitor and power supply. Typically, two television monitor units without generator or battery packs weighed 25 to 40 pounds (depending on screen size) and were 15-20 inches wide by a foot in height and depth. Addition of a small generator (35 lbs.) or 2-3 battery packs (approximately 35 lbs.), the receiver/decoder, the control panel, and the antennas make it infeasible for an individual to carry and operate the console without a vehicle. Inclusion of a switcher in the remote vehicle will produce a split screen display at the console, thereby requiring only one monitor. However, due to losses in picture, a larger-screened monitor may be needed using AC input. The net gain in this system is the reduced cost of using only one microwave transmitter and receiver set (instead of one for each camera) and the ease with which the operator can view driving and detection conditions. The split screen can be wiped to show full screen view from either camera.

The control panel, shown on next page, would have adjustment controls for aiming each camera, two lever controls for driving the vehicle, gages for engine and hydraulic system monitoring, a



STANDARD MFG. CO., INC.

DRAWING TITLE

BLOCK DIAGRAM CONTROL CONSOLE

CODE IDENT NO	SIZE	DRAWING NO
98296	C	9

lever for wiping images on the monitor, and an area of tape dispenser controls. Inclusion of a frequency/channel selection control will probably be necessary to permit use of several RPGV's in the same area. If the mine removal feature is included on the vehicle, the controls for this equipment is included in a separate area on the panel. The vehicle control block of the panel could be designed for removal when the operator intended to ride the vehicle. This block could then connect by cable to the vehicle, by-passing the radio systems.

The monitor and control panel are best mounted together in a desk-like configuration. Folding legs enable emplacement in small spaces, such as in a jeep, as well as in an APC or the bed of a truck. This feature also improves storage and transportability characteristics. Mounting the monitor at an angle improves operator visibility without raising the screen to eye level. It may be possible to fold the operator's control panel up against the monitor screen and enclose the package in a protective container. This protective container could be strapped to the RPGV on top for shipping, airmobile operations, or towing. A portable generator and antenna mount could also be stored in the case for use with the control unit. The remainder of the control antenna could clip or strap onto the RPGV, completing the system in mobile configuration.

4.2.2.3 Boom Assembly for Detector Systems.

In order to clear a standard lane through a minefield using an single system, some device is needed to swing the detector at least four meters to each side. This will insure a near nadir viewing angle at the edge of the lane, with some area beyond the lane also being tentatively scanned. This border area is desirable for insuring safety if the RPGV needs to turn left or right to avoid a mine cluster. Increasing the armature length will decrease the required sweep angle, thereby decreasing the complexity of the pan mechanism and increasing possible detector heights. Increasing the detector height yields an increase in scan width and an increase in vehicle speed for a slight sacrifice of resolution and reflected signal strength. These increases also benefit system survivability and must be balanced against the difficulty of fine control and the strength requirements for the armature.

Boom composition may need to be non-metallic to prevent detonation of metal sensing devices. Plastic, fiberglass, and Kevlar reinforced laminates are potential materials for use in the boom. By using a hinged configuration, inactive boom length can be halved, making its storage on the vehicle possible during airmobile transport. Further shortening of the boom for storage may be possible if a telescoping system is used. Storage of this type of boom may be accomplished by retracting the boom and mount under the sloped armor plate. This would provide much more protection for the detectors than an armored storage box which would probably be developed for security and transport of detectors mounted on a hinged boom. The hinged boom design would be stronger, probably less expensive, and may be easier to develop due to materials properties. Any material used in the telescoping boom would have to be resistant to hydraulic fluid damage and protected more from small arms fire. Either design can be made in a system lighter than one made of steel.

The boom would be mounted on a turntable bearing race thereby permitting rotation of the camera through a full circle. This will permit aiming the camera to the rear for backing the RPGV out of places where it is not possible or desirable to turn around immediately.

4.2.2.4 Marking Mines and/or Cleared Lane.

4.2.2.4.1 Current Techniques Overview.

Detection of mines is only of value if the mines are neutralized, marked for passage of friendly forces and removal by engineers, or immediately removed as an obstacle. Currently, the Army has rollers, flails, and SLUFAE for neutralization of mines by detonation. Use of this technique is not always desirable due to tactical situations and destruction of equipment. Explosions in an area where the enemy has emplaced mines will alert him of an attack being conducted through that area depriving U.S. forces of the element of surprise and subjecting our forces to additional hostile fire. Although rollers are less expensive than a detection and removal vehicle, system deterioration due to mine detonations may result in destruction of the roller-equipped vehicle as it encounters the other rows of mines in the minefield. Also, rollers are not effective against all types of mines. The effectiveness of SLUFAE in neutralizing magnetically activated minefields has not been indicated in support documents. Each of the detonating techniques has a speed advantage over the mine detector vehicle and should not be discarded; however, the hazards and drawbacks indicate the need for a reliable covert system as well.

4.2.2.4.2 Mine Marking.

Marking of individual mines can be accomplished by placing a flag or survey stick alongside the mine. A piece of florescent tape or paint would enable drivers to see these markers at night. Placement could be accomplished from the detector arm assembly or, if used, from the mine removal equipment armature.

Feasibility of mine detection and marking without removal should be examined, however. In cases where the minefield has been bypassed and is in a rear area, engineer removal of the mines is standard. Destruction in place is common practice to avoid loss of life removing mines emplaced with antihandling devices. Removal of the mines by the remote detector would not be necessary for this purpose. A remote control armature could be used to move surface laid mines to insure that they are not booby-trapped and could excavate buried mines without endangering soldiers. The salvaged mines could then be deployed by our forces, when needed. Although removal capability is nice to have, remote control detection and marking of mines remains the only essential function when the vehicle is used in rear echelon areas.

4.2.2.4.3 Lane Development.

4.2.2.4.3.1 Reasons for Consideration.

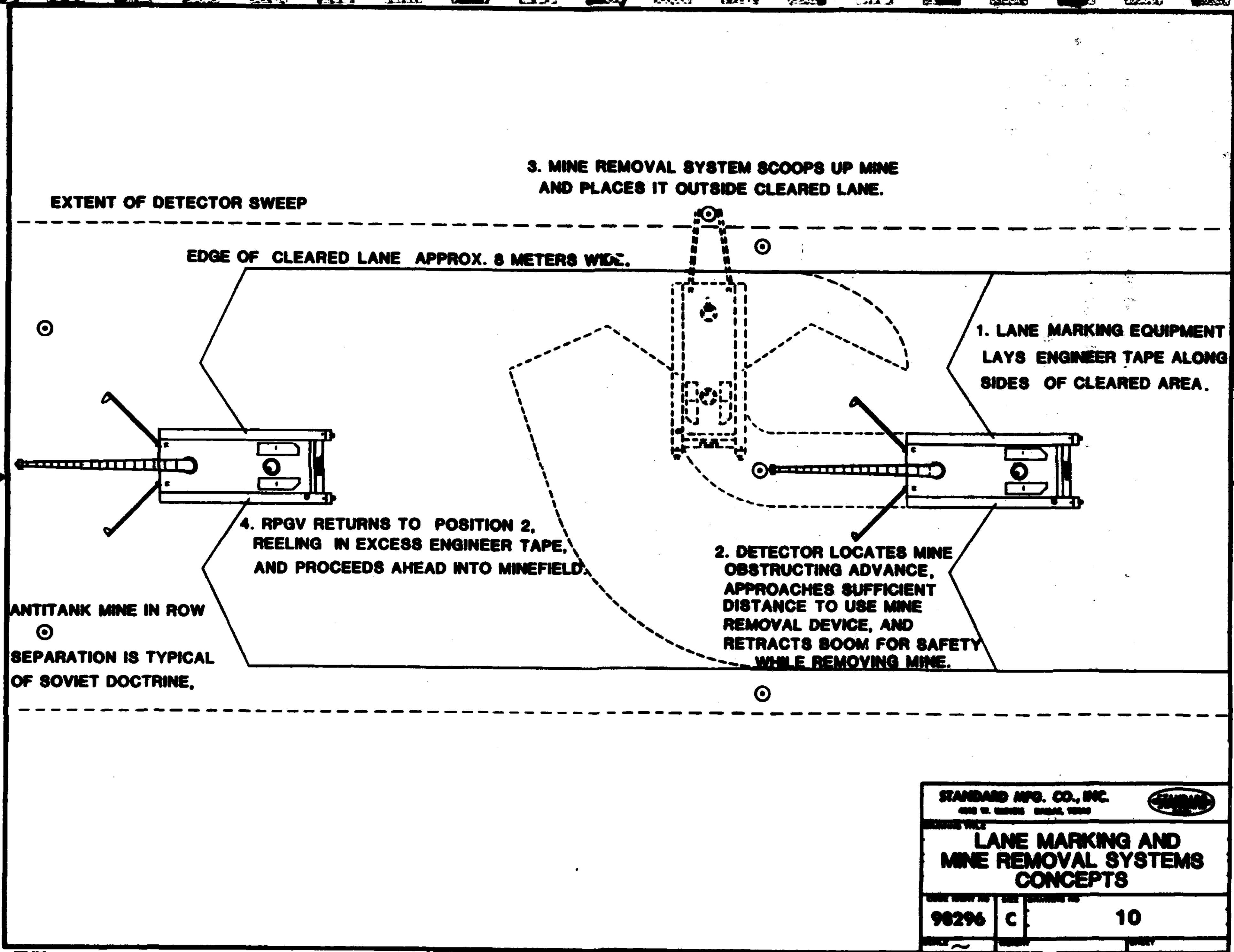
Mine removal takes on additional importance when the vehicle is used to support an attack through a mined area. Soviet mine laying equipment places mines at 4 to 5-1/2 meter intervals for antitank mines, with additional rows of mines to insure one mine for each meter of frontal area in the minefield. Even if a diagonal or zig-zag lane is marked through the field, vehicles such as the M1 tank, which is 3.7 meters wide, will not be able to negotiate the path without detonating mines. The M1, for example, would detonate mines under both tracks if it attempted to drive between mines spaced 4 meters apart. Allowing for decreased driver visibility while operating under combat conditions (i.e., protective mask, with hatches closed, using night vision equipment), the resulting cleared lane through the minefield may need to be much wider. U.S. Army countermine doctrine calls for one-way vehicle lanes to be 8 meters wide (removing one mine per row as laid by Soviet vehicles) and widening of the lanes after the assault to 16 meters for two-way traffic. A six to eight meter wide lane is called for by Soviet doctrine, also indicating a requirement to have the increased width. Movement of the mines to the eight meter width does not add any more requirements than to six meter spacing and is, thereby, desirable because of increased safety of vehicles using the lane.

4.2.2.4.3.2 Lane Marking Techniques.

Hasty marking of the lane can be accomplished by laying of engineer tape. The simplest means of doing this is to merely attach a reel to the rear of the mine detector indicating where it has gone through the field. Deviations from the axis of travel are minimized (i.e., when changing course to go around a cluster of mines or when moving a mine out of the lane). Operability of this method is poor, however. With good fortune, the first vehicles following the detector would straddle the tape without destroying it under a track and following vehicles would stay on the track marks of the leaders. It can be expected that, in combat, exact straddling of the tape and following of tracks would not happen. The travelled area would gradually widen until it exceeded the cleared lane.

Laying tape at the sides of the lane would not be as susceptible to being covered and would define the limits of the cleared area. A boom mount arrangement also permits marking along the front of a minefield without driving as close as with a one-roll tape-dispensing system. The improved capability would require additional equipment. Folding booms would be needed to reach to the sides of the lane and a slack tape take-up system becomes necessary during maneuvers. Envisioned solution operated like a fishing reel. Weights are periodically tied to the tape anchoring it at the edge of the lane. The reel take-up system keeps the tape reasonably taut to the point where the next weight is added. The weight is designed to be sufficiently heavy to overcome the reel drag brake and, like a fish, to pull out the tape. This apparatus would prevent confusing tape patterns from developing when the detector turns to move a mine or backs up a short distance to avoid a mine cluster (see drawing on next page).

To enhance tape visibility, changes to the tape (i.e., color, florescence, etc.) or the weight system are possible. A type of robotic arm arrangement could plant survey sticks, posts,


3. MINE REMOVAL SYSTEM SCOOPS UP MINE AND PLACES IT OUTSIDE CLEARED LANE.
EXTENT OF DETECTOR SWEEP
EDGE OF CLEARED LANE APPROX. 8 METERS WIDE.
1. LANE MARKING EQUIPMENT LAYS ENGINEER TAPE ALONG SIDES OF CLEARED AREA.
4. RPGV RETURNS TO POSITION 2, REELING IN EXCESS ENGINEER TAPE, AND PROCEEDS AHEAD INTO MINEFIELD.
2. DETECTOR LOCATES MINE OBSTRUCTING ADVANCE, APPROACHES SUFFICIENT DISTANCE TO USE MINE REMOVAL DEVICE, AND RETRACTS BOOM FOR SAFETY WHILE REMOVING MINE.
ANTITANK MINE IN ROW
SEPARATION IS TYPICAL OF SOVIET DOCTRINE.
STANDARD MFG. CO., INC.
LANE MARKING AND MINE REMOVAL SYSTEMS CONCEPTS
98296
C
10

highway reflectors or use lights instead of simple weights. Other changes to Army engineer tape may permit use of different systems for tape dispensing. Lead weights strung or glued to the tape would provide anchoring characteristics desired. A drive-system actuated device may then be feasible reeling out tape when that side of the vehicle rolls forward, reeling in tape when vehicle is in reverse. Some irregularity would develop in lane marking as the tape may not remain on a straight line after conducting maneuvers.

The boom assemblies would probably be tubular fiberglass or plastic, possibly laminated Kevlar, thereby maintaining low weight characteristics, housing the tape and weight dispensers, and keeping a high level of survivability. Optimum mounting is toward the front of the vehicle permitting storage of folding type booms on top of the wheel skirts. Mounting near the detector also minimizes the chance of cutting a corner when turning thereby indicating a cleared edge of lane beyond the sweep of the detector. Care must be taken by the operator so that any mine removal equipment does not get tangled with the tape when placing an excavated mine beyond the side of the lane, a potential problem which increases in accordance with how far forward the booms are anchored. With the booms anchored at the front of the vehicle, for example, a 90 degree turn will lay tape in an arc around the vehicle center. The front of the vehicle is now pointed toward two strips of tape which, for clear lane marking, the operator must avoid in depositing a scoopful of mine and earth. When the detector returns to its course through the minefield, the excess tape is reeled in.

4.2.2.4.3.3 Lane Clearing Equipment.

Mine removal, either by an engineer unit in a secured area or at the front lines by any available means, will always be very hazardous. Due to the use of antihandling devices on mines, mechanical removal and destruction in place are preferred means of eliminating a minefield over using personnel. To date, the only safe mine removal device has been a scraper blade mounted on an armored vehicle. With the operator safely behind armor plate, the mine is bulldozed out of the ground. The envisioned mine detector does not have the power necessary to accomplish this type removal work and it is very undesirable to increase the vehicle's horsepower, weight and size. The loss in maneuverability and utility decrease usefulness and survivability, and the larger vehicle would cost more. In order to find a potentially suitable system, current commercial excavating devices were evaluated for possible revision. Clamshell, backhoe, and paddle blade systems were eliminated due to probability of mine detonation. Metallic, seismic, and pressure sensing detonators could all be activated by these systems. Tree removal equipment, like the backhoe systems, appeared to satisfy low available power requirements but, prior to increased study, seemed likely to activate metallic sensors. When it was learned that two bladed excavators are made as well as three and four bladed systems, the possibility of using a similar digger was studied. A two bladed system is more desirable because of plug extraction without passing a portion of the extractor over the mine. Theoretically, it will also extract mines without as exacting requirements for positioning because distance from the detector will not affect the location of radially aligned blades. This is desirable due to possibly indefinite mine location, difficulty of determining depth perception on a flat television monitor, and the need to swing the detector armature away from the mine while excavating to prevent damage in case of mine detonation. Operational tests will need to be conducted to determine concept feasibility and types of materials that can be used in the extractor. A plastic may be required to foil metal detection detonators.

4.2.2.5 Other RPGV Equipment and Mission Capabilities.

When not in use as a mine detector, the inherent capabilities of the vehicle make it desirable for use accomplishing several other important missions. Reconnaissance in front of friendly forces is easily done utilizing the television cameras. Inclusion of the recommended zoom lens and night vision equipment extend operational limits in this area. A second inherent application is for towing hazardous cargo or delivering materials to a hazardous area. In order to protect the detector system during hazardous missions, a system can be developed to retract the boom under the sloping armor plating. This retraction feature is also desirable when passage through the minefield is completed due to the potentially close range of opposing forces.

Optional or attachable equipment for the vehicle includes smoke generators, grenade launcher pods, Geiger counter, chemical agent detectors, laser target designator and rangefinder equipment, and possibly even a small platform mounting an antitank missile (similar to designs being tested by the West German army). The smoke generators and grenade launcher pods would enhance vehicle survivability and aid the accompanying U.S. unit in combat situations by reducing the enemy's detection capabilities and preventing sapper-type attacks on the detector. As a remote control vehicle, the detector is ideally suited for missions into nuclear and chemical contamination areas. These trips can be to check hazard levels or to take supplies to survivors in shelters. Depending on desired attachments to the detector probe, it may even be used for collecting samples or disposing/neutralizing small areas of contaminants. Inclusion of the laser rangefinder and target designator systems enable the detector vehicle to operate in the same role as Martin-Marietta's Tadpole target acquisition and designation system identifying and designating targets while concealed behind a hill, building, or trees.

Additional missions may develop as the vehicle's capabilities are proven. For example, if the vehicle is amphibious, it may be used to string cable across a river, assisting engineers build a bridge.

4.2.2.6 Mission Equipment Characteristics.

Various combinations of the described items of mission related equipment yield different RPGV mission capabilities. A careful balance of performance, cost, survivability, utility, and value indicates the probable optimum systems for inclusion in the system. In order of importance, these are:

1. Infra-red scanner type detector using camera system display.
2. Navigation camera.
3. Boom for detector with traverse system.
4. Side of lane marking system.
5. Light intensification system for cameras.
6. Mine neutralization or removal system.

Costs for each of these vehicle subsystems can vary drastically. Frequently, however, savings in initial costs are offset by much higher replacement rates and by the increased probability of breakdown under severe wartime operating conditions. Perhaps the best example of this condition is in the television and infra-red cameras. A basic tube type T.V., similar to portable home video models, can be purchased for under $1000.00. Comparison to the state-of-the-art portable unit for television broadcast companies reveals several significant differences. The broadcast model has approximately twice as fine picture resolution, is smaller and lighter, is not susceptible to damage if pointed toward the sun or magnesium flares, uses metal oxide semiconductors which are much less likely to be affected by rough handling, and costs approximately $11,000.00. Each of the areas of major improvement is significant in military application, and it is concluded that the additional initial expense is required to insure reliability and reduce maintenance expenses. Survival of the RPGV and following vehicles is dependent on quality in all areas. Initial costs for various systems on the RPGV can be expected to be as shown on next page.

Diesel engine and hydraulic pumps	$10,000.00
Undercarriage	7,500.00
Metal components (frame, body, etc.)	10,000.00
Ballistic protection	10,000.00
Detector boom (Robotic)	70,000.00
Lane marking booms (10,000 each)	20,000.00
Mine removal/neutralization devices	10,000.00
Navigation and detection verification/ .... IR detector cameras (11,000 each)	22,000.00
Television transmission and receiving system	
1) Using one monitor and split screen ...	49,500.00
2) Using separate monitors for .... navigation and detection	82,500.00
Radio control system	15,500.00
Light intensification systems for cameras ...... (6,000 each)	12,000.00
Fabrication costs	24,500.00
Total initial cost using IR Detector capability inherent in a T.V. camera	
1) Using split screen system	$261,000.00
2) Using separate television monitors ...	$294,000.00

Further study may indicate desirability of a radar detector system, an image stabilizer, and fiberoptic devices also, but that information is not developed at this time. Costs for these components would be approximately:

Radar system	$80,000.00
Image stabilizer	30,000.00
Fiberoptic devices	10,000.00

The optional equipment listed in section 4.2.2.5 is recommended for inclusion on a detachable mount, special mission usage basis or on specially made vehicles. The range of RPGV activities is currently quite diverse and it will continue to increase as technology develops new equipment. For example, when the scientific state-of-the-art develops a camera system capable of duplicating the functions of the human eyes and optic nerve, a remote control vehicle will be able to replace any comparable manned vehicle. It will perform its functions under man's guidance while protecting him with a stand-off distance from the hazardous area.

REFERENCES

"Quantification of the Relative Military Worth of Alternative Countermine Systems (U)", Technical Report No. BDM/W-79-745-TR, Submitted under Contract DAAK70-77-D-0023, T.O. No. 31, The BDM Corporation, McLean, VA, 1 December 1979, UNCLASSIFIED.

Y. Morita, G. Suits, H. McKenney, and I. Sattinger, "Identification and Screening of Remote Mine Detection Techniques (U)", Report No. 138300-22-T, Environmental Research Institute of Michigan, Ann Arbor, MI, 26 June 1979, UNCLASSIFIED.

H. McKenney, "Remote Detection of Minefields, Volume 1 (U)", Report No. 138300-65-F1, Environmental Research Institute of Michigan, Ann Arbor, MI, September 1980, UNCLASSIFIED.

MERADCOM DEP 5-6665-294-10, Detecting Set, Mine Vehicle Mounting AN/VRS-5(V), Draft Technical Manual, December 1980, UNCLASSIFIED.

P.M. Pecori, "Portable Mine Detector (AN/PR5-8)(U)", Report No. 2329, Submitted under Contracts DAAG-53-C-0062 and DAAK-70-77-C-0134, MERADCOM Countermine Laboratory and Cubic Corporation, June 1981, UNCLASSIFIED.

TM 5-6665-293-13, Detecting Set, Mine, Portable Metallic and Nonmetallic (Litton Systems MDL AN/PRS-7) FSN 6665-179-5120, September 1969, UNCLASSIFIED.

IAG-13-U-78, Soviet Army Operations, U.S. Army Intelligence and Threat Analysis Center, Arlington, VA, April 1978, UNCLASSIFIED.

TM5-6665-202-13, Detecting Set, Mine: Aural Indication; 10VDC Operating Power: Portable Transistorized, W/Case AN/PSS-11, December 1971, UNCLASSIFIED.

FM 20-32, Mine/Countermine Operations at the Company Level, 30 November 1976, UNCLASSIFIED.

Dean R. Freitag, "A Dimensional Analysis of the Performance of Pneumatic Tires on Soft Soils", Technical Report No. 3-688, Vicksburg, MS, U.S. Army Engineer Waterways Experiment Station, August 1965, UNCLASSIFIED.

J. G. Kennedy and E. S. Rush, "Trafficability of Soils, Eighteenth Supplement", Technical Memorandum No. 3-240, Vicksburg, MS, U.S. Army Engineer Waterways Experiment Station, March 1968, UNCLASSIFIED.

E. S. Rush and J. H. Robinson, "Trafficability of Soils, Nineteenth Supplement", Vicksburg, MS, U.S. Army Engineer Waterways Experiment Station, April 1971, UNCLASSIFIED.

A. A. Rula and C. J. Nuttall, Jr., "An Analysis of Ground Mobility Models (ANAMOB)", Technical Report No. M-71-4, Vicksburg, MS, U.S. Army Engineer Waterways Experiment Station, July 1971, UNCLASSIFIED.

William P. Baxter, Lt. Col., USA, Ret., "Soviet Mine Warfare, Army's 'Silent Death'", Army, Association of the United States Army, Arlington, VA, July 1982, UNCLASSIFIED.

FM 30-102, Opposing Forces Europe, 18 November 1977, UNCLASSIFIED.